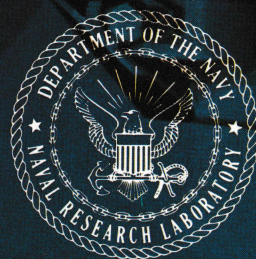
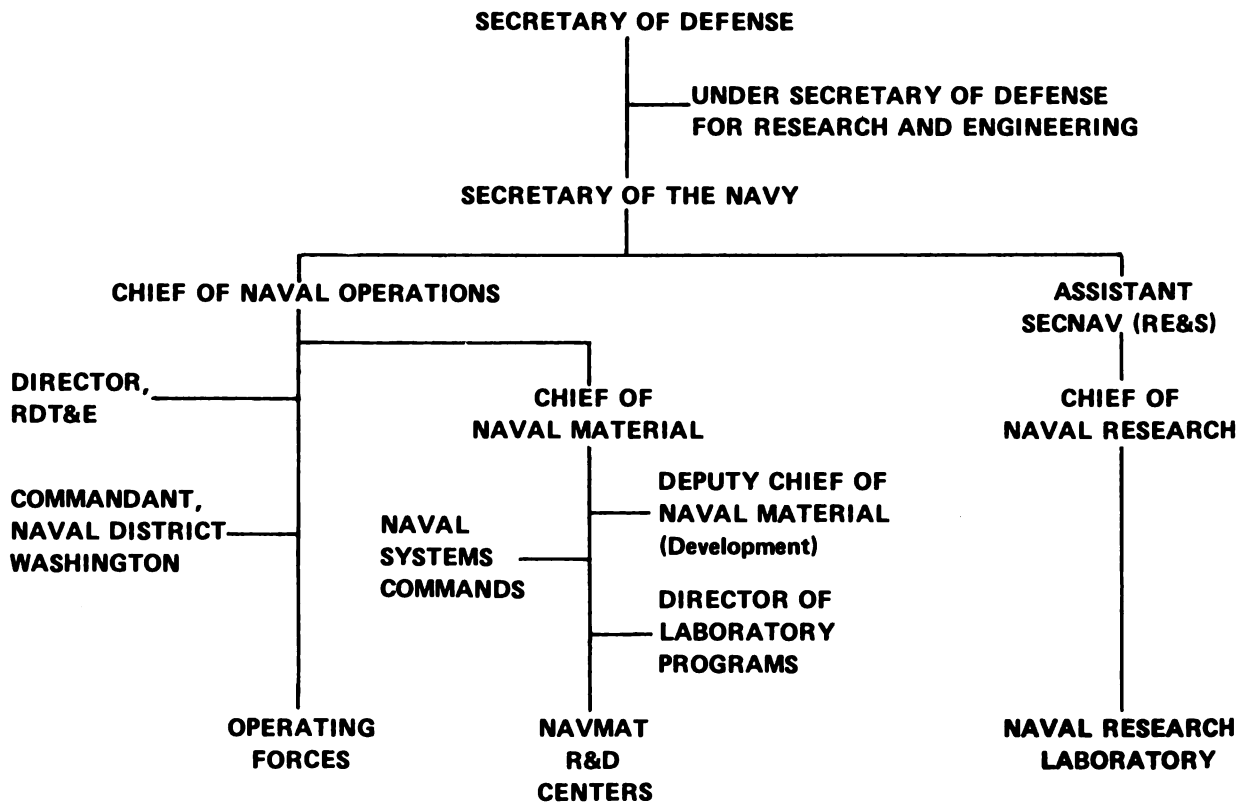


1978 REVIEW



NAVAL
RESEARCH
LABORATORY
WASHINGTON, D.C.

Approved for public release; distribution unlimited.



NRL in the Department of Defense (December 1978)

Cover photo—Large vacuum chamber area of the Spacecraft Technology Center's Payload Checkout Facility. In the foreground, Wilbert Barnes (right) and Joseph Inzana confer in front of the thermal vacuum chamber. On the back cover, John Shepherd checks a test setup for installation in the rough vacuum chamber, while Roy Harding (above) adjusts the high vacuum chamber. The Payload Checkout Facility also has equipment for mechanical and acoustic vibration test, spin balance, and mass properties measurement.



REVIEW

AN ACTIVITY OF THE OFFICE OF NAVAL RESEARCH



MISSION

The mission of the Naval Research Laboratory is to conduct a broadly based multidisciplinary program of scientific research and advanced technological development directed toward new and improved materials, equipment, techniques, systems, and related operational procedures for the Navy. In fulfillment of this mission, the Naval Research Laboratory:



Initiates and conducts scientific research of a basic and long-range nature in scientific areas of special interest to the Navy.

Conducts exploratory and advanced technological development deriving from or appropriate to the scientific program areas.

Within areas of technological expertise, develops prototype systems applicable to specific projects.



Performs scientific research and development for other naval commands and, where specially qualified, for other agencies of the Department of Defense and, in defense-related efforts, for other government agencies.

Upon request from appropriate naval commands, assumes responsibility as the Navy's principal R&D center in areas of unique professional competence.



Provides to the Navy and its contractors standardized techniques and procedures for measurements and the accurate calibration of standard instruments in areas of special Navy needs.

Furnishes scientific consultative services for the Navy and, where specially qualified, for other agencies of the Department of Defense and, in defense-related efforts, for other government agencies.



Provides to the Navy determinations of performance characteristics of developmental and prototype devices through limited engineering test and evaluation services.



PREFACE

During 1978 we witnessed changes of command both here at the Laboratory and at our headquarters command, ONR, along with many changes in both staffs. However, the multidisciplinary nature of the Laboratory work remains as steadfast as ever. The fifteen research divisions, the three designated staff laboratories, and the several staff groups so attest. But organizational names on a flow diagram do not produce results—it is the people, the dedicated people within the organization, who conceive, nurture, and develop the ideas that provide the results, be they reports, journal articles, patents, or demonstration models. In the end, it is people that count.

On any one day in 1978, we had about 3,500 people on board with about 2,000 in the four research directorates and the remainder in the Support Services Directorate or the front office staffs. Research and support are a team, and although we have focused on the former in this *Review*, we believe that the importance of the latter is apparent throughout the pages.

Naturally, our primary customer is the U.S. Navy through various sponsors—the Chief of Naval Research, the Chief of Naval Material, the Systems Commands, and other laboratories—but the diversity of our capabilities allows us to serve a variety of other customers including the U.S. Army, U.S. Air Force, NASA, Department of Energy, industry, and academia.

We believe that, regardless of who the customer is, the various tasks we are pursuing have relevance to Navy problems—broadly stated, anticipated problems which are based on present facts and projected trends. The key to solving these problems is innovation, but the measure of our success in its use must wait until our research is completed and tested in the Fleet. Until that time, we can look back on our many successes and predict that our team will continue to perform. At NRL, dedicated

work based on fundamental science is what produces the new systems and techniques of tomorrow.

As you read this *Review*, we hope you will agree that NRL's people continue to be innovative and imaginative and that their efforts are contributing to the well-being of our Nation today as they have for the past 56 years.

Capt. E. E. Henifin, USN
Commanding Officer
Naval Research Laboratory



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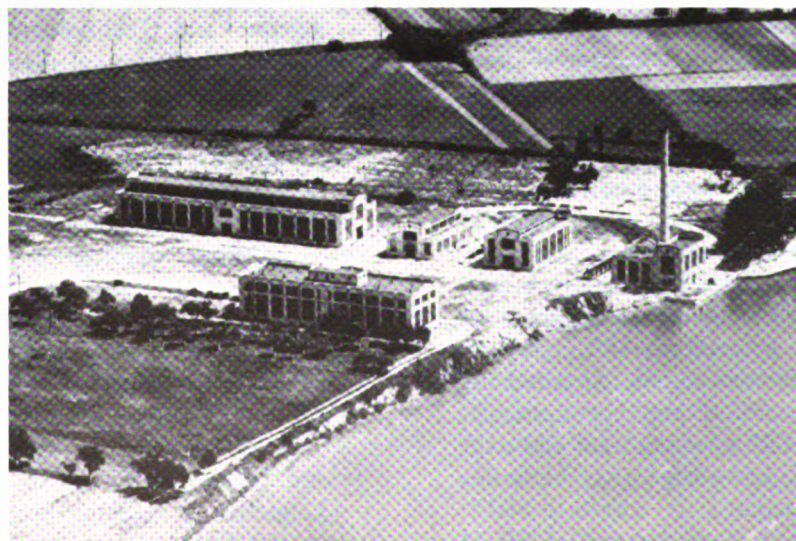
THE LABORATORY—PAST AND PRESENT

Historical Background

In the present age of cryogenics, lasers, spacecraft, computers, and intensive scientific study in innumerable laboratories, it is difficult to recall the state of research in the Navy before World War I. New ideas and devices came primarily from the work of independent inventors, so that technological progress was piecemeal and unsystematic. Thomas Edison, while commenting on the growing importance of science to modern warfare in an interview in the *New York Times Magazine* on May 30, 1915, argued that the Government needed its own research laboratory to keep the armed forces well prepared. Reading the article and seeing an opportunity to enlist the help of the great inventor, Secretary of the Navy Josephus Daniels created a Naval Consulting Board of eminent engineers with Edison as its President. Building a laboratory soon

became the major project of the Board. Funding was obtained in 1916, but delays due to the War postponed the project. Finally the Naval Research Laboratory opened on July 2, 1923, at its present site in the southern tip of the District of Columbia.

NRL began operations with a research staff of 24 men in two divisions: Radio and Sound. The radio investigators studied ionospheric propagation; they developed the high-frequency band and established it as the principal means for long-distance military communications. They added much to the basic knowledge of radio technology and developed a variety of communications equipment, including that successfully used on the famous Navy dirigible, *Shenandoah*, from 1924 to 1925. These early NRL scientists discovered the principle of radar, developed the Navy's early radar equipment, and designed efficient units in time to make important contributions throughout World War II.



NRL's original buildings in 1923

Meanwhile, the underwater acoustics experts successfully studied their medium and produced effective sonar systems that greatly enhanced the Navy's operations. Also, they cataloged the sonic noise patterns (signatures) of U.S. Navy ships, thus providing an important tool for distinguishing between friendly and hostile vessels.

Inevitably, the Navy's needs and NRL's eagerness to explore new areas caused the Laboratory to branch out beyond the two original fields of research. By 1941, on the eve of World War II, there were NRL divisions working not only in radio and sound, but also in metallurgy, chemistry, mechanics and electricity, physical optics, and internal communications.

After Pearl Harbor, the war dominated life at NRL and brought the greatest changes yet experienced by the facility. These are most apparent in the dramatic expansion that occurred during the war years.

	1941	1946
total employees	396	4400
expenditures (millions)	\$1.7	\$13.7
buildings	23	67
research projects (approx)	200	900

Much of this increased effort was naturally directed to applied science—the quick solution of immediate practical naval problems. When victory finally eased the pressure for such wartime responses, NRL investigators were able to give more attention to longer term, basic studies in such fields as molecular structure, the details of chemical and physical processes, radiation, magnetism, the properties of materials, and many aspects of the naval environment of sea, atmosphere, and space. Although such basic research is sometimes curtailed by changes in the political and economic climates, it has proved its worth over and over by providing the knowledge that underlies effective applied science.

In the 33 years since the end of World War II, new scientific fields and technologies have opened up at an accelerating tempo,

and NRL has kept pace, seeking new information and applications of relevance to the Navy. Thus have radio and x-ray astronomy, satellites, plasma physics, solid state physics, lasers, fiber optics, cryogenics, microcircuitry, computer science, and other young fields come within the Laboratory's purview. Accordingly, at the end of 1978 NRL had 15 research divisions and detachments and about a half-dozen smaller specialized laboratories to carry out its mission.

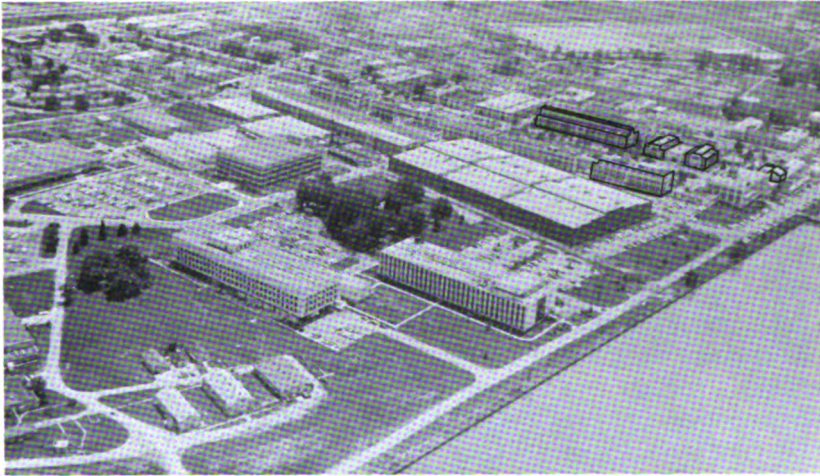
The remainder of this section provides some basic information about NRL in 1978, including the Laboratory's administrative organization and its physical plant, field stations, major research platforms, and significant equipment.

Administration and Organization

The Naval Research Laboratory is under the overall direction of the Chief of Naval Research, who reports directly to the Assistant Secretary of the Navy for Research Engineering and Systems.

The Laboratory is commanded by a Navy Captain, who is directly responsible to the Chief of Naval Research. The scientific work is headed by a civilian Director of Research. He is assisted by four Associate Directors of Research who supervise work in the broad scientific fields of NRL's four Science and Technology Directorates that address the areas of Electronics, Materials and Radiation, Space and Communications, and Oceanology. A Superintendent, who reports to the appropriate Associate Director of Research, supervises the work of each of the 15 research divisions and detachments.

Offices relating to the Laboratory's management, personnel, finances, security, military concerns, public affairs, and other administrative matters report directly to the Commanding Officer. Procurement, construction, operation and maintenance, engineering services, technical information, and other services in support of the Laboratory's research program are provided by the Support Services Directorate, which is headed by a Navy Captain who reports to the Commanding Officer. The resources of



A major portion of NRL as it appeared in 1978. The original buildings are outlined on the right.

this directorate include mechanical and electronic engineering staffs; drafting and design capabilities; machine, sheet-metal, welding, metal-casting, plating, pattern-making, electronic, and plastic shops; and staffs for writing, editing, photographing, illustrating, printing, and disseminating the Laboratory's many publications and presentations. The NRL Technical Library, which contains about 140 000 bound volumes, over 350 000 documents (hard copy and microfiche), and subscribes to some 2000 periodicals, is an outstanding resource for the Laboratory staff.

The funds for research, equipment, supplies, and supporting services come from the several Navy Systems Commands, the Office of Naval Research, and other governmental organizations that contract for the individual scientific and engineering tasks performed at the Laboratory. In fiscal year 1978, the Navy-sponsored research tasks comprised 85.6 percent of the Laboratory's actual obligations. NRL's total fiscal 1978 research obligations were \$194.5 million.

Personnel

The distribution of regular full-time NRL employees as of December 31, 1978 was:

Military	
Officers	39
Enlisted	101
Total	140
Civilian	
Scientific and Engineering	1403
Technical Supporting	647
General Admin. and Clerical	654
Wage Board	621
Total	3325

The highest university degrees held by permanent employees as of December 31, 1978, are summarized in the following table:

Bachelors	576
Masters	365
Doctors	583
Total Employees with Degrees	1524

Some of these degrees were obtained under a variety of advanced study programs that are sponsored by the Laboratory to enhance the proficiency of its personnel. These programs are described and the participants named in the last part of the section entitled "Recognition of Personnel."

Field Stations

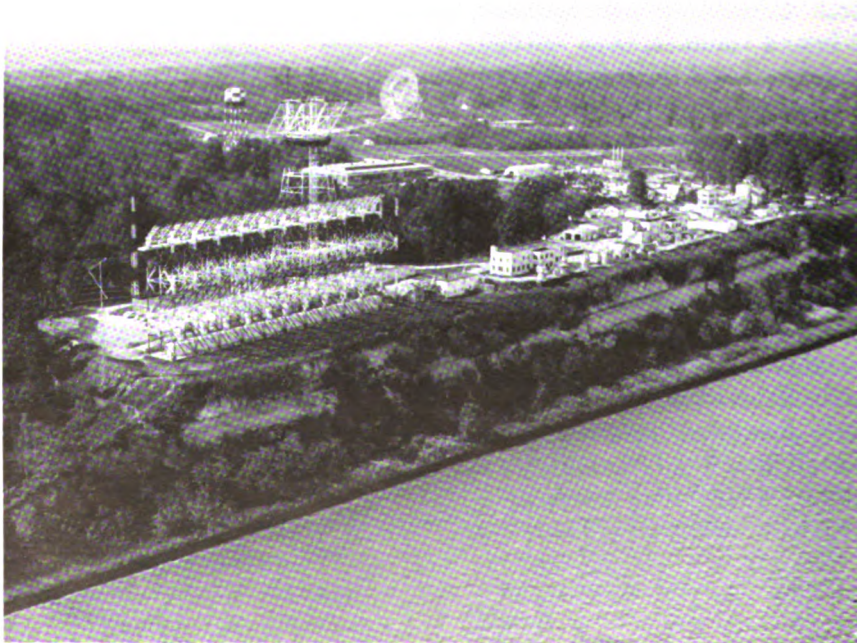
The main Laboratory in Washington, D.C., includes 14 research divisions and the

major portion of their extensive facilities and supporting services. Over the years, NRL has acquired or made arrangements to use a variety of field sites and auxiliary facilities to carry out and support specialized research that cannot be conducted in the Main Laboratory. The field stations are located in Maryland, Virginia, California, Florida, and Puerto Rico. The geographic scope of research is expanded still farther by means of an oceanographic ship, aircraft, and missions of research teams that go far afield for eclipses, rocket and satellite launches, troubleshooting, and a variety of special activities. The two largest field stations are the Chesapeake Bay Detachment (CBD) and the Underwater Sound Reference Detachment (USRD).

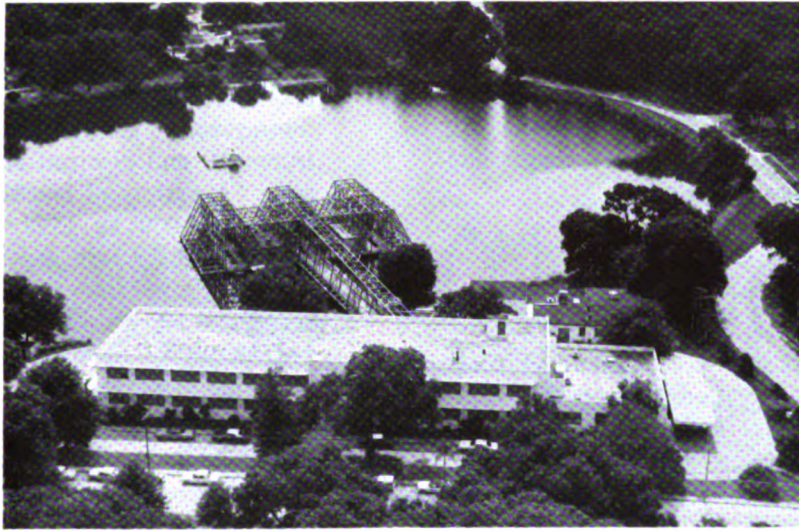
CBD, which occupies 68.1 hectares (170 acres) near Chesapeake Beach, Maryland, provides facilities and services for research in radar, fire-control equipment, optical devices, materials, communications, and other fields. For these investigations

CBD has a 45.7-m (150-ft) steerable parabolic microwave antenna, a hypervelocity gun for studying ballistics penetration into various materials, several radars, including NRL's long-range over-the-horizon radar, and other equipment that includes off-base instrumentation. Furthermore, the Detachment operates boats up to 19.2 m (63 ft) and uses an over-the-water optics range with one terminal at CBD and the other on the eastern shore of the Bay at Tilghman Island.

The Underwater Sound Reference Detachment of the Oceanology Directorate is located at Orlando, Florida. The semi-tropical climate and two clear, tranquil lakes are distinct assets in conducting research and development on underwater reference standards and in improving techniques to calibrate, test, and evaluate underwater acoustic devices. USRD has developed the most complete facilities in the world for underwater sound measurements and has supplied acoustic equipment and calibration services



A part of the Chesapeake Bay Detachment facilities



Underwater Sound Reference Detachment, Orlando, Florida

to hundreds of Navy activities and their contractors and to allied governments.

A number of field sites have been chosen primarily because they provide favorable conditions for the operation of specific antennas and electronic subsystems. Maryland Point, Maryland, has two radio telescopes with antenna dishes 25.6 m (84 ft) and 25.9 m (85 ft) in diameter for radio astronomy research; NRL's Waldorf facility has an 18.3-m (60-ft) X-band antenna and an S-band antenna of the same size for space and communications research. Pomonkey, a third field site in Maryland, has a free-space antenna range for the development and testing of a variety of antenna types. Another facility used in improving communications is the Antenna Model Measurement Range in Brandywine, Maryland. Here model ships scaled 48 to 1 can be set up and rotated in the center of a range 305 m (1000 ft) in diameter to provide data that aid in theoretical and experimental antenna design. The Laboratory has installations for satellite tracking in Blossom Point, Maryland, and at Vandenburg Air Force Base in California.

The Laboratory conducts marine corrosion studies in Key West, Florida, and owns or leases a number of small sites and instal-

lations for recording data and conducting specialized investigations in accordance with the current requirements of sponsors.

Research Platforms

USNS HARVEY C. HAYES, which is named after the Laboratory's pioneer in underwater acoustic research, is a catamaran 75-m (246-ft) long that has a loaded displacement of 3475 metric tons (3420 long tons). This weight is up from that reported when the ship first went into service seven years ago, because more equipment has been installed and an underwater foil has been added. During 1978 HAYES carried out oceanographic missions in the western Atlantic from Florida to Massachusetts and sailed as far east as Bermuda.

For airborne experiments, NRL uses four propeller-driven aircraft specially equipped for research in atmospheric physics, radiometric measurements, oceanographic surveillance and acoustics, electronic warfare, and other areas of investigation supported by sponsoring organizations. The aircraft include two four-engine turboprop P-3A "Orions," a two-engine S-2D "Tracker," and a four-engine EC-121K "Super Constellation," all based for the most part at the

Naval Air Station in Patuxent River, Maryland. During the year, some of the aircraft went as far as Florida and California, and one of the "Orions" flew to Sicily and later ranged as far west as Perth, Australia. In 1978 the four aircraft made 400 flights and logged 1736 hours in the air.

Other Facilities

The Laboratory has outstanding tools for research in radiation science and technology. A 1.93-m (76-in.) diameter sector-focusing cyclotron, located just outside the Main Laboratory, can deliver protons of 70 MeV and other particles. In addition to radiation-damage and nuclear-scattering experiments, clinical tests for the treatment of cancer have been carried out at the cyclotron by using intense neutron beams generated by 35-MeV deuterons. Other major facilities include a 65-MeV linear electron accelerator, a 5.5-MV, positive-ion Van de Graaff accelerator, a 2-MeV electron Van de Graaff accelerator, a 14-MeV neutron generator, a 200-kV ion-implantation accelerator, and two high-level cobalt-60 radiation sources. A high-level radiation facility, which has a shielding capacity of 10 000 curies at 1 MeV, is used for investigations of changes induced in the properties of metals by neutron radiation.

NRL has many outstanding facilities for studying the characteristics of materials and improving them for a variety of purposes. A facility producing very high steady magnetic fields allows study of electrical, optical, and other properties in fields up to about 200 kOe (kiloOersteds). Water-cooled magnets have been, and still are, used to generate these fields. Also used is a facility with a superconducting-type magnet capable of 150 kOe in a room-temperature working bore of 64-mm diameter. It will soon be connected to a continuously operating, helium liquefier. The newest addition is the superconducting section of a hybrid magnet. This unit, capable alone of reaching 68 kOe in a room-temperature bore of 270-mm diameter, will, with the addition of a water-

cooled section, make steady fields near 240 kOe available at NRL.

Facilities are available for transmission and scanning electron microscopy, x-ray fluorescence analysis, spark-source spectrometry, and electron and Auger spectroscopy. A variety of machines with capacities up to 272 000 kg (598 400 lb) for testing fatigue and fracture are used to investigate and improve new high-strength, high-toughness alloys; other devices are available for corrosion fatigue studies.

The Laboratory has many lasers and uses them for developing improved lasers and as tools in a wide variety of research. The highest power device, which has produced more than 0.5 TW (terawatt), is a very large glass-laser facility consisting of a variable pulse-width, dye-switched Nd:YAG oscillator operating through a bank of Nd:glass amplifiers for final output. There is a continuing program of upgrading and characterizing this instrument for extensive investigations of the interactions of laser beams and matter. The device with the greatest energy is a CO₂ electric-discharge laser that provides continuous-wave radiation; it is used in conjunction with Navy materials research programs.

Plasma physicists also use lasers in investigations of the properties of extremely hot gases. High-power magnetic-compression facilities are used to produce confined deuterium plasmas of multimillion-degree temperatures. The Laboratory also operates a number of high-current relativistic electron-beam generators. The largest of these, called Gamble I and Gamble II, are used for the study of high-current beam interactions, the generation of high-current ion beams, and the simulation of x-rays in weapons-effect studies.

A modest yet interesting optical science tool is NRL's facility for drawing research-quality optical fibers. This device—the first of its kind in the Department of Defense—is used in the preparation of a variety of glass- and plastic-clad optical fibers in 0.5-km (545-yd) lengths.

Acoustic interactions with structures are studied in a 511-m³ (135 000-gal)



Computer room of the Research Computation Center

research tank. This tank and its instrumentation make it possible to immerse models of various shapes and materials, subject them to acoustic radiation, and study the strength and character of the echoes that are produced. The results are valuable in improving antisubmarine-warfare devices and techniques. A companion air-acoustic facility permits separation of geometric and elastic effects. A minicomputer associated with both facilities permits computer control of experiments as well as direct analysis of data.

Among the NRL facilities for developing, testing, and monitoring satellites and for conducting space navigation experiments are several satellite tracking and telemetry stations and a navigation-satellite calibration facility. Rockets and orbiting observatories acquire data for astrophysical research, and supporting facilities aid in interpreting the results and in calibrating instruments.

NRL uses numerous computers, from small units that are integral parts of various research facilities to large general-purpose systems that serve the entire Laboratory and outside users. The Texas Instruments Advanced Scientific Computer (ASC), operated by the Research Computation Center (RCC), has a two-pipe central processor, one million words of high-speed bipolar central memory, and 450 million words of disk storage. The ASC is one of the most powerful data processing systems in the country; its capabilities are made readily available to users *via* various means of access and are enhanced by an optimizing Fortran compiler and a wide assortment of software. The RCC provides timesharing service to NRL by means of the DECsystem-10, which is based on a PDP-10 central processor with 256 000 words of memory. Mass storage capacity of 1.16 billion characters and a large selection of 7

software make this system useful to many scientific and administrative units. Other computing systems at NRL offer appropriate capabilities for almost any kind of data processing that may be required.

Expansion and Construction

As the years pass and science expands dramatically, the Navy and other NRL sponsors call upon the Laboratory to delve more deeply into traditional disciplines and to master new fields. Accordingly, NRL has had to assemble the facilities and the personnel to advance with the many technologies essential to the preeminence of our Navy. This has called for new construction, demolition of outdated and uneconomical structures, and adaptation of old buildings to new uses. In 1962, NRL completed a study of its current and future needs and drew up a long-range program for modernization and expansion on a priority basis. The cyclotron building (built on the more solid ground of Bolling AFB nearby), three other major research buildings, an administration and support building, and a modern heating plant were completed by early 1974. Later in that year, ground was broken for the first of three parts of a new laboratory for elec-

tronic warfare research. In mid-1978, work was completed on the second portion of the building, which contains a \$3 million Central Target Simulator. This complex core facility is installed in an anechoic chamber, and is used for testing the effectiveness of a variety of weapons and electronic devices against selected enemy configurations of equipment. The last part of the building will house the Electromagnetic Development Laboratory and is scheduled for completion in 1980.

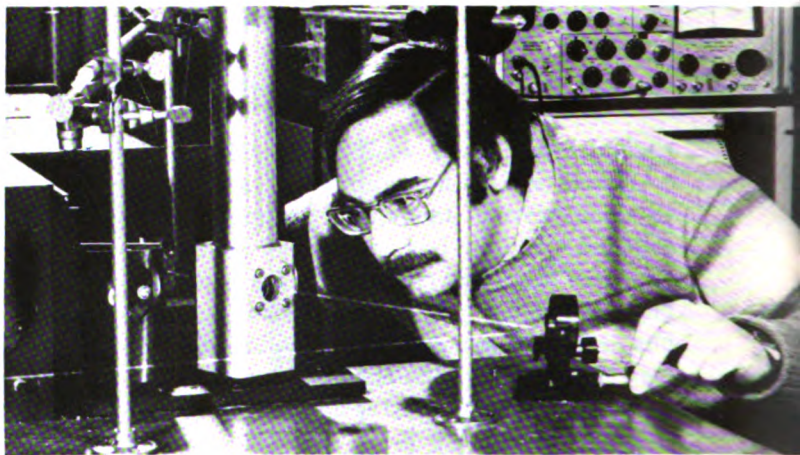
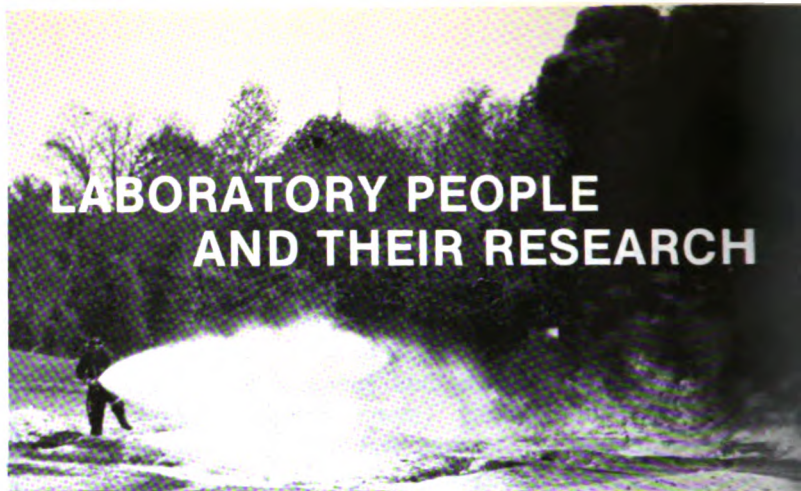
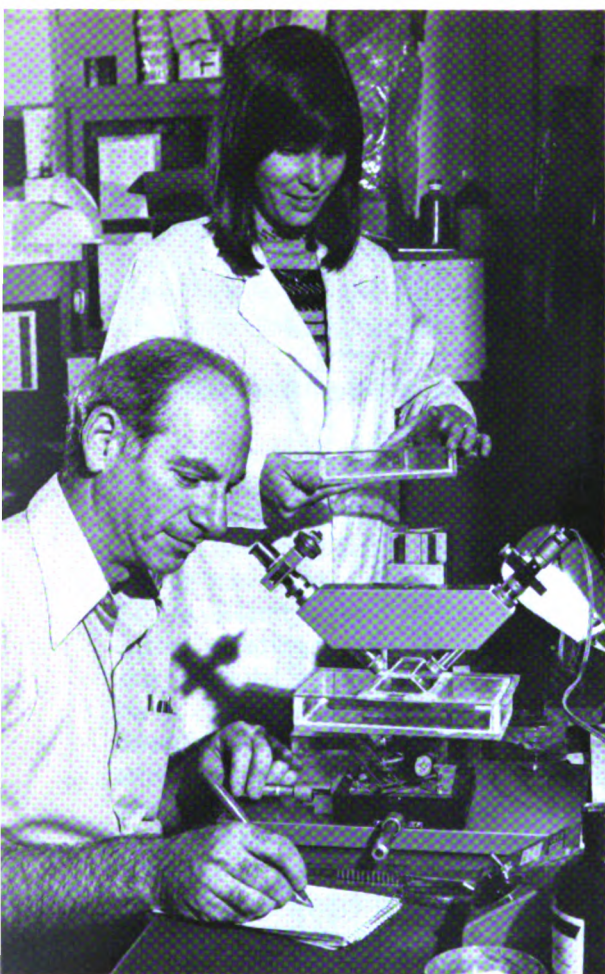
Further Information

The *NRL Fact Book* gives more details about the Laboratory and its operations. It lists important equipment, current fields of research, field sites, and outlying facilities and presents information about the responsibilities, organization, key personnel, and funding of the divisions, detachments, and other major organizational units. Copies are available by request from:

Commanding Officer
Attention Code 2627
Naval Research Laboratory
Washington, DC 20375



9



Reading clockwise from upper left.

C. A. Bailey (right) assists G. I. Loeb with film growth measurements. See pages 183 and 185.

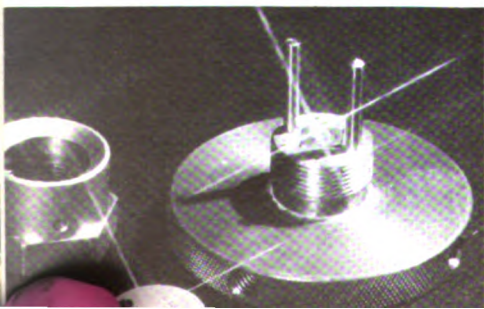
NRL-developed "light water" is used to suppress an experimental fire at CBD as part of the Laboratory's fire-suppression program. See page 181.

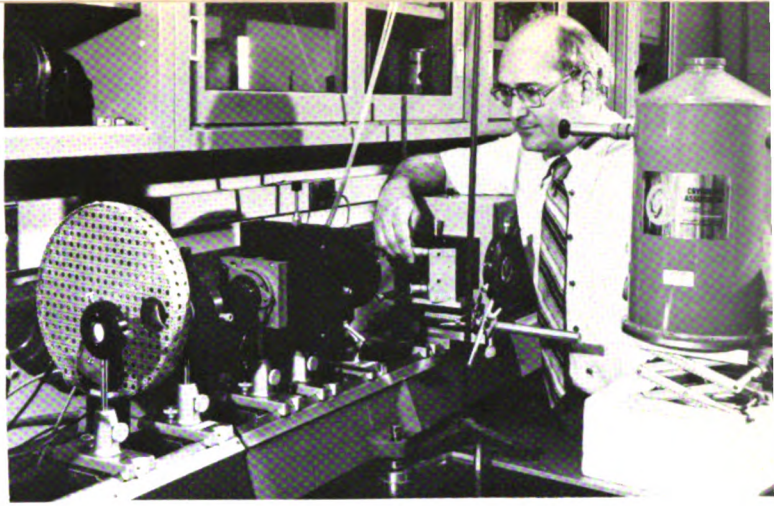
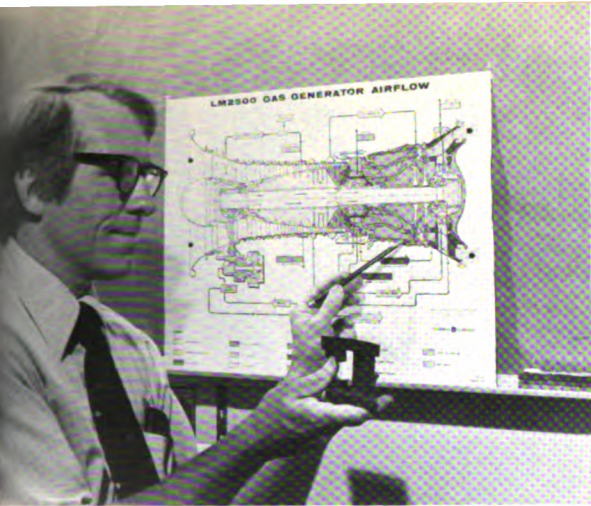
Paul B. Klein adjusts photoluminescence apparatus.

S. G. Gathman sampling artificial fog by aircraft. See page 31.

Diamond high-pressure cells. See page 152.

A. D. Elia adjusts antenna for multipath measurements. See page 62.





Reading clockwise from upper left.

R. L. Jones indicates the location of the corroded turbine vane (in his hand) on a SPRUANCE-class destroyer's gas generator system.

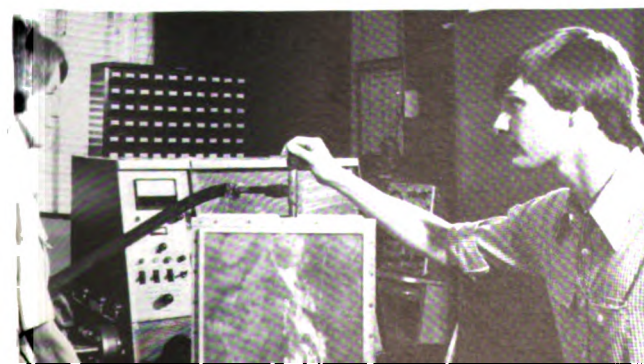
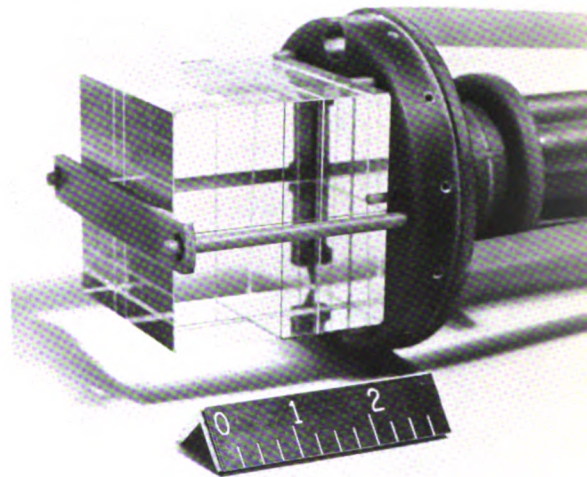
M. Daehler adjusts a piezoelectrical interferometer to be used for measuring nebular observations.

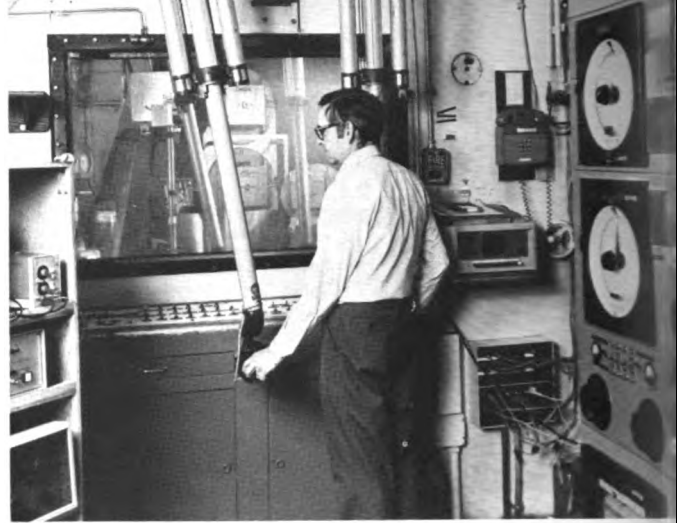
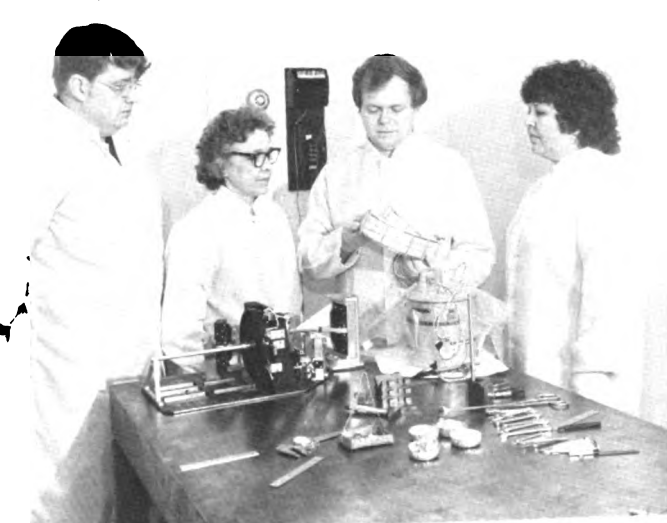
SQUID antenna wound on quartz block. See page 89.

Launching buoyancy package for acoustic source. See page 49.

L. P. Beahm (left) and J. Bellingham test the heavy ion space experiment for leaks.

C. A. Carosella adjusts the beam from NRL's ion implanter. See page 161.





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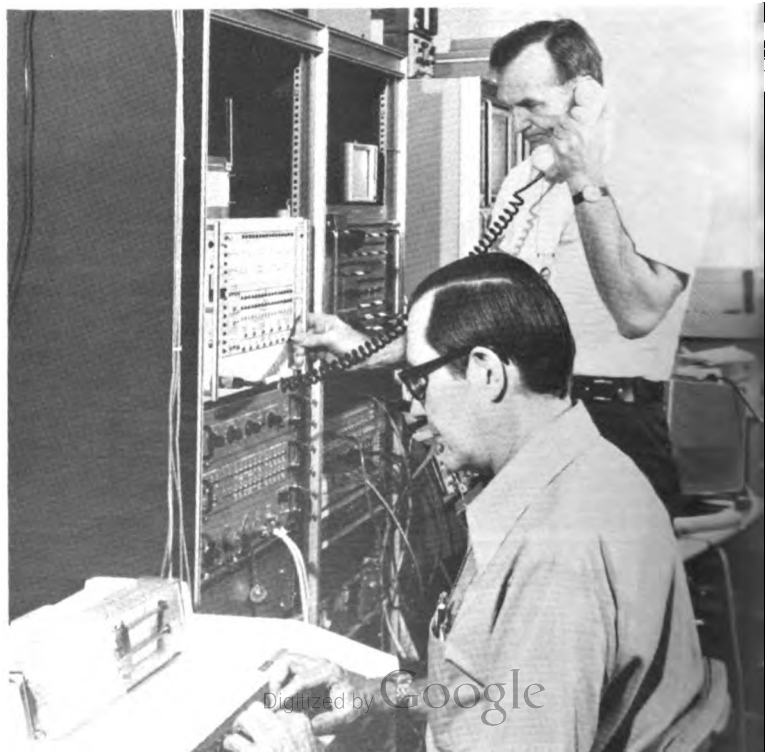
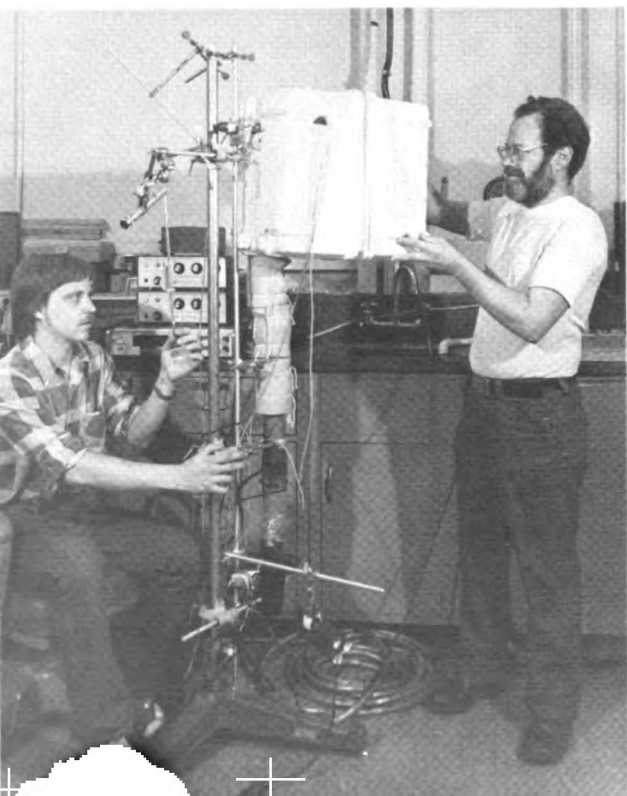
C. E. Morgan, D. Fravel, D. L. Blizzard, and S. Allen work on the final assembly of NRL's Solar Ultraviolet Spectral Irradiance Monitor instrument.

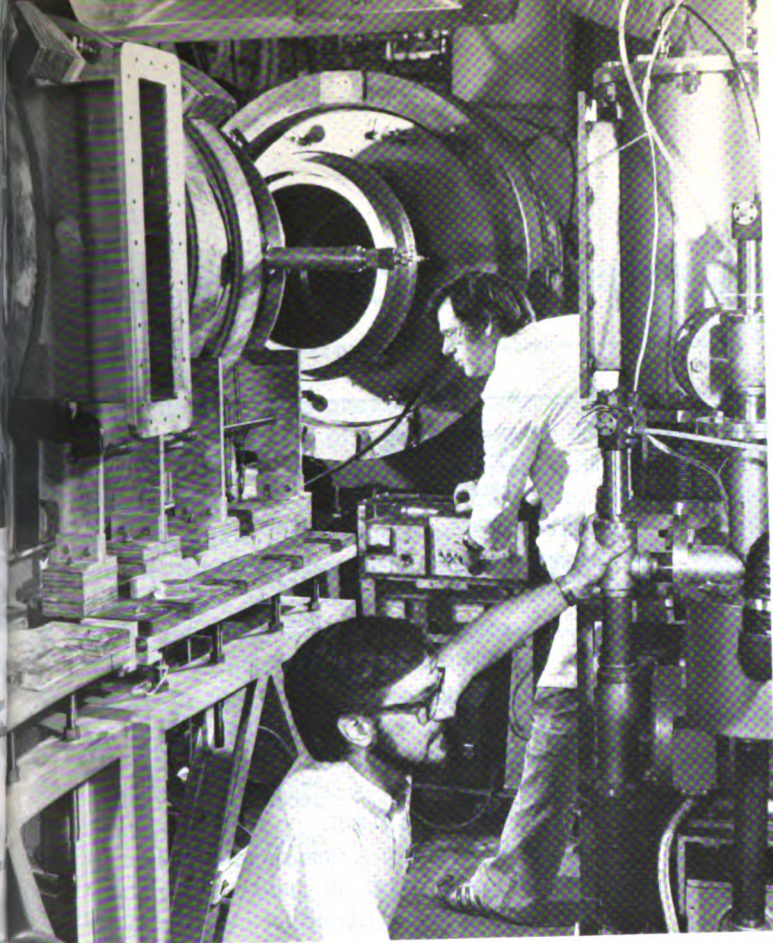
W. E. Hagel manipulates samples in NRL's "Hot Cell."

A. F. Thornhill (foreground) and J. P. Ihnat work with an advanced narrowband digital voice terminal.

J. A. C. Kaiser (right) and E. Kneer assemble air temperature and dew point probe. See page 21.

J. P. Dugan measures vertical extent of ocean eddy. See page 23.





Reading clockwise from upper left.



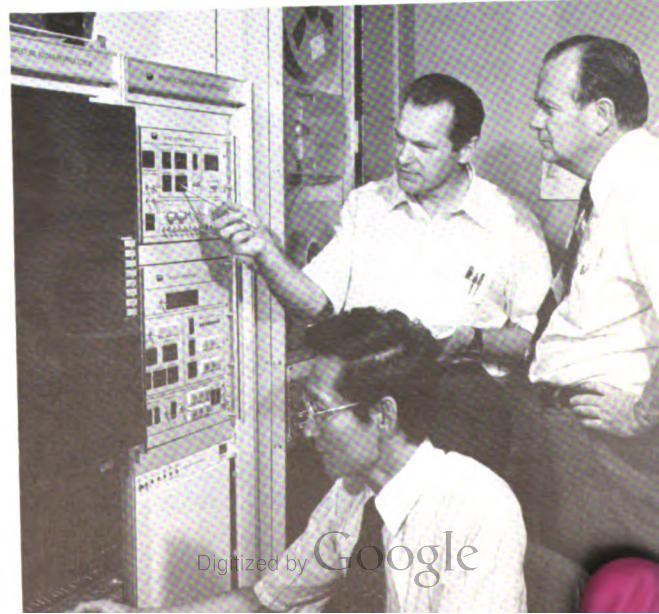
J. Golden (foreground) and S. J. Marsh prepare the apparatus of the NRL Ion Ring Experiment.

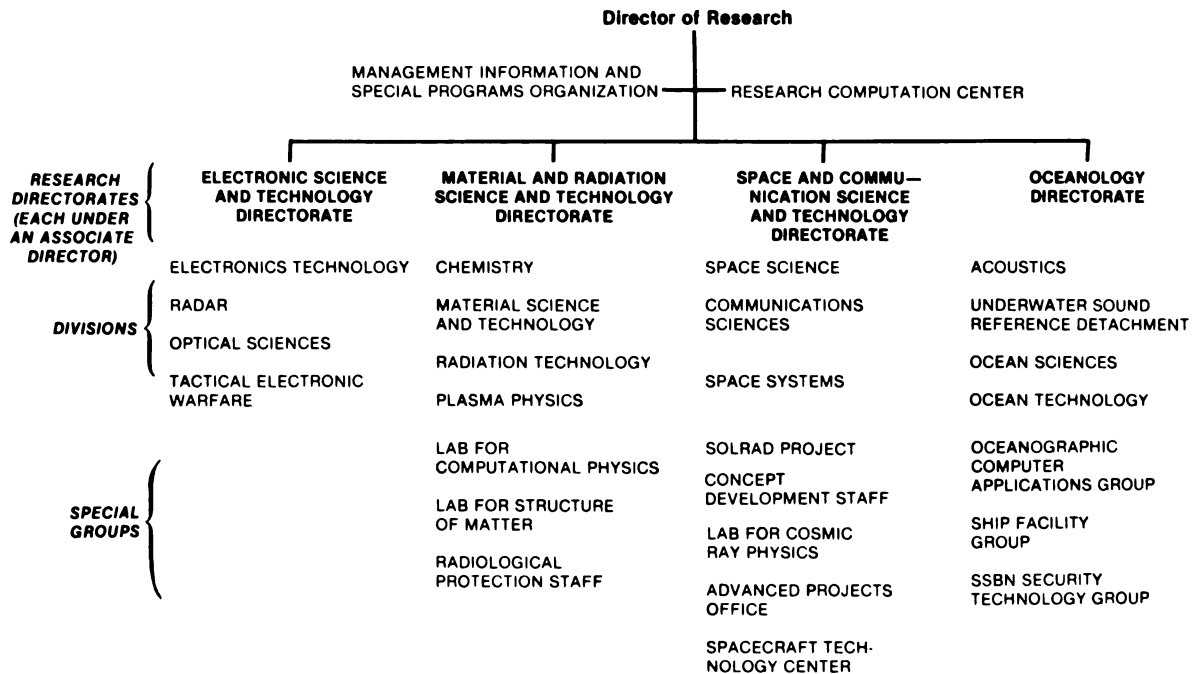
V. A. Del Grosso adjusts underwater laser/camera. See page 103.

P. G. Moore (left) and J. H. McDermott adjust the apparatus and target in the High Power Laser Facility.

J.-S. Lee (seated) and I. Jurkevich (center) demonstrate the synthetic aperture radar processor system to A. F. Petty.

Terry Donahue uses a CW argon ion laser to separate cerium from a mixture of rare earths.





Organization of the Research Directorates, 1978

THE NRL PROGRAM—RESEARCH AND PROGRESS

The year 1978 marked the 100th anniversary of the founding of a great industrial laboratory by Thomas Edison. One of Mr. Edison's objectives was to establish an organization that could generate inventions that would result in the granting of at least one important patent per week. Since Mr. Edison also was instrumental in the founding of the Naval Research Laboratory, it is interesting to examine our performance in the light of his original precepts for his own laboratory.

A review of NRL's rate of patent applications over the last few years shows that, over its recent history, this Laboratory has indeed exceeded Mr. Edison's quota of one patent a week. But that is only one measure of effectiveness. Although we do devote consider-

able time and attention to the generation of patentable ideas, the appropriate measures of productivity of a laboratory such as NRL must include the publications in the open or classified literature, the serious Navy problems that have been resolved, and the briefings to high-level Navy and other DoD officials which conveyed ideas, concepts, and solutions to serious military problems. Certainly, the indices of NRL activities in each of these domains have been impressive. In 1978, there were approximately 618 NRL publications in the open literature and 604 presentations by NRL staff members at various national and international meetings. Our scientists and engineers published 250 NRL Memorandum Reports and there were 49 patents granted to NRL personnel and assigned to the U.S. Government. The specifics of these activities may be found in the Contributions section of this *Review*.

Since Mr. Edison's days, the concept of a laboratory, whether university, industrial, or government, has evolved significantly. The staff at NRL is not an isolated group working only with fellow civil servants. They interact with professionals from academia, industry, nonprofit research institutions, and other government laboratories. People come to NRL from universities and foreign laboratories to spend one or more years in collaborative research; in turn, NRL personnel spend significant periods of time working in other laboratories both in the United States and abroad. The continuing cross-fertilization, interchange of ideas, and critical examination of concepts produced by these interactions have contributed immeasurably to the vitality, intellectual richness, and productivity of the Naval Research Laboratory. Our pattern is not unusual. In fact, we doubt that any major laboratory can be productive, in the modern sense of the word, if it depends solely on the activities of its own staff. Collegial interactions across the entire range of scientific and engineering activities are central to the intellec-



Dr. Alan Berman
Director of Research
Naval Research Laboratory

tual viability of any laboratory. NRL management has encouraged the Laboratory staff to increase these interactions by every available mechanism, and the results of this policy are quite evident in the following pages.

Adhering to the precedent established last year, we have subdivided this review of our efforts into ten general categories. Each of these areas has reflected impressive and significant advances.

In the ocean environment, NRL scientists report significant progress in understanding the thermal dynamics of the upper ocean. Our studies of techniques for global monitoring of petroleum pollution of the ocean, our enhanced knowledge of the thermal structures of ocean fronts and eddies, and our understanding of current-induced forces on ocean structures all will have significant impact in the fields of ocean science, engineering, and naval operations.

The section that presents some of our work related to ocean acoustics also reports impressive progress. The experiments on acoustic propagation in regions of high gradients show extremely good agreement with our modeling results. In general, steady progress

has been made in modeling propagation using realistic representations of the ocean bottom and using three-dimensional variability in the acoustic velocity structure of the ocean. Significant progress also can be reported in our understanding of the acoustical behavior of coated steel plates and in the use of composite materials for acoustic applications.

Traditionally, NRL has invested considerable effort in the important areas of information processing, transmission, and analysis. This level of effort was actually increased in 1978. A number of papers on information theory and applied probability were published, and we believe that some represent major advances that may change currently accepted approaches to problems in these areas. NRL's efforts toward the development of robust HF communications, the understanding of microwave multipath effects, and the development of narrowband digital voice terminals also resulted in significant progress. In recent years, the cost of software engineering has tended to be the driving economic factor in new system developments. Some interesting and exciting approaches to the application of new software engineering techniques are reported herein that



The Research Advisory Committee has responsibility for the scientific program and meets frequently with the Commanding Officer. Pictured from left are Mr. R. E. Ellis, Mr. R. R. Rojas, Dr. H. Q. North, Dr. H. Rabin, Capt. E. E. Henifin, Commanding Officer, Dr. A. Berman, Director of Research, Dr. L. F. Drummeter, Dr. A. I. Schindler, and Mr. A. J. Hollings. Mr. Rojas, Dr. North, Dr. Rabin, and Dr. Schindler are, respectively, Associate Directors of Research for NRL's four Science Technology Directorates that address the areas of Oceanology, Electronics, Space and Communications, and Materials and Radiation. Mr. Ellis, a senior staff member, is head of the Management Information and Special Programs Organization. Dr. Drummeter is Associate Superintendent of the Optical Sciences Division. Mr. Hollings is Executive Assistant to the Commanding Officer and to the Director of Research.

may result in important cost and time savings in software development programs.

The effects and beneficial applications of radiation are areas of long-standing interest and productive activity at NRL. Radiation effects in optical fibers may ultimately limit their use in space-based systems. The effects of radiation-induced defects in III-V semiconductor material are also quite central to the survivability of complex electronics systems in a space environment. During 1978, we have continued our investigations of radiation diagnostic and analysis techniques and believe that we have achieved a better understanding and recognition of the principles involved. Finally, the effects of gamma radiation on charge-coupled devices (CCDs) have been studied extensively. If the effect of gamma rays on these devices can be understood and controlled, then CCDs can be employed in radiation environments where they will provide interesting and important new surveillance capabilities.

Since its beginning more than 50 years ago, NRL has made many important contributions to the development of electronic and optical technologies. The year 1978 witnessed striking advances. The development of field emission arrays for cathodes represented one of the most important of these advances. Considerable progress was made in our ability to measure the optical properties of the ocean and its atmosphere, and there have been important contributions to radar reliability and antenna research and development.

As in past years, NRL's 1978 involvement in space-related activities was quite significant. While much of that work cannot be reported in this document, brief accounts of NRL's participation in Navy space studies, modernization of the Navy's space surveillance system, and some results of satellite observations are presented. On a purely scientific basis, our outstanding success has been the performance of the HEAO 1 satellite. This satellite has been used to identify radiating sources that may result from the existence of black holes. Confirmation of such discoveries will not only have a profound effect on man's perception and understanding of cosmological processes, but will also affect our understanding of high-energy plasma processes here on Earth.

A naval-related laboratory such as NRL must expend significant effort in the development of new techniques of power generation. In 1978, there was important progress in our work on the gyrotron for high-power millimeter wave source applications. NRL gyrotron developments will have interesting applications in such diverse fields as surveillance radars, electronic warfare, tactical battlefield target designators, and plasma heating devices for fusion. NRL efforts in the area of fusion research are oriented toward the development of possible compact fusion devices for naval applications, such as propulsion, and there has been considerable progress in our plasma and astrophysical investigations.

The U.S. Navy must always seek improved capabilities with which to carry out its many mission responsibilities. In this regard, the Naval Research Laboratory recognizes the all-pervading value that improved materials can contribute to the performance of U.S. Navy platforms and systems. Some novel results are reported herein. Our scientists have developed a unique method for surface hardening of bearings by ion implantation that should result in extended and improved service lives for many Navy systems. Progress in laser-welding of thick steel plate promises better and faster welds, and appears to have important economic value for the fabrication of ships, aircraft, submarines, and weapons for our Navy. NRL scientists also have fabricated carbon fibers with improved electrical conductivity, and have achieved some very striking developments and applications for second-generation phthalocyanine resins.

In 1978, Laboratory programs included a variety of efforts to improve the Navy's ability to analyze materials and to understand their behavior under different environmental conditions. The optical characterization of ion-implanted silicon, the recognition of grain size importance in cracking resistance in titanium, the discovery of a new turbine blade corrosion mechanism, and an exact analysis of guyed towers are examples of this sort of activity.

In the final analysis, the Navy is an organization that depends on its people and must strive to improve the conditions and quality of their working environment. In 1978, NRL con-

tinued major programs in such diverse areas as shipboard fire detection, systems for analysis and purification of air in submarines, the improved radiobiological damage estimates, and accurate dose distribution calculations for fast-neutron therapy.

A report of this type cannot present a complete picture of the Laboratory's operations and accomplishments. Much of our work on systems and applications of our scientific results to naval platforms and weapons is not

addressed. And, our classified contributions are omitted entirely of course. Beyond such obvious omissions, we cannot adequately convey the immense contributions of our staff in the form of advice, consultations, and emergency services to the Navy and to other defense and civilian organizations. Nevertheless, we present this report to our readers as a representative sample of a broad and imaginative research program oriented toward the solution of Navy problems.

THE OCEAN ENVIRONMENT



THE OCEAN ENVIRONMENT

Environmental conditions and effects rank high among the many complex and interrelated factors that affect mission success at sea. NRL scientists are working in many areas to understand these effects and to provide the knowledge and means to predict, mitigate, or avoid them in order to improve the Navy's ability to function effectively in, on, and over the world's oceans.

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Upper Ocean Thermal Dynamics, by J. A. C. Kaiser, *Ocean Sciences Division*

The Navy has a continuing interest in the upper boundary (or mixed) layer of the ocean, its effect on immediate operational requirements, and its exploitation for future Navy needs. Depth and temperature variations of the duct-like mixed layer affect acoustic propagation. The thermal dynamics of the mixed layer govern the production of sea fog and sea ice. For non-acoustic ASW, an understanding of how subsurface oceanic processes affect the skin temperature and the upper few millimeters of the ocean is crucial. Remote infrared sensors measure this skin temperature. Mixed layer thermal processes also couple the deep ocean to the atmosphere and play a key role in climatic fluctuations with time constants of several years or greater.

A natural scientific approach to understanding the mixed layer of the ocean is to study its heat and mass transfers. These transfers embody the physics of the mixed layer and determine its horizontal, vertical, and temporal variability.

The mixed layer forms as a result of wind mixing and is warmed by virtue of solar heating. In summer, it usually is separated from the ocean below by a well-defined interface or thermocline. The heating is strongest just below the ocean surface and is spatially and temporally variable. This variability of heating (and cooling of the ocean surface, mainly by evaporation) generates horizontal and vertical fluxes of heat in the water. Diurnal variation of upper ocean temperature due to the daily cycle of solar heating causes the heat fluxes in the water to vary diurnally. The vertical component of the heat flux is due to wind-generated convection and turbulent mixing, and the horizontal flux is carried by ocean currents. The vertical heat flux is a major factor in determining the temperature at and near the ocean surface.

Vertical heat flux was determined for the first time as a function of depth in the upper ocean from a set of measurements made in the Sargasso Sea in September 1974. The necessary data included solar heating as a function of depth and time, $i(z,t)$, and the rate of change of the heat stored in the water $h_t(z,t)$. The net

heat flux per unit depth was then calculated from the heat balance as

$$f(z,t) = i(z,t) - h_t(z,t)$$

and includes both horizontal and vertical components. In the upper few meters, the horizontal fluxes can be neglected, so $f(z,t)$ is essentially the net vertical flux per unit depth.

The rate of change of stored heat is determined from a time series of temperature profiles in the upper ocean at a single location (Figure 1). From this series of profiles, the heat stored at each depth as a function of time was determined, and the rate of change at each depth was then calculated as a time derivative.

Downgoing radiation as a function of depth is determined from measurements of solar radiation at the ocean surface and at the 5-m depth, and from a simple radiative transfer model. The downgoing radiation as a function of depth, $Iu(z)$, normalized with respect to the downgoing radiation at the ocean surface, I_s , is shown in Figure 2(b). All the data for one day are coalesced into one graph. At the surface ($z = 0$ m), the ratio $Iu(z)/I_s$ is always one. Below the surface, it is always less than one and, at any fixed depth, varies considerably with cloud cover variations and the daily cycle of solar elevation.

Solar heating as a function of depth, $i = \partial Iu(z)/\partial z$. Figure 2(a) shows the solar heating normalized to a fixed surface value of the downgoing radiation. The very rapid decrease just below the ocean surface is due to the fact that the incoming solar radiation is composed of many wavelengths and some are absorbed much more readily by seawater than others.

To illustrate the heat balance, it is averaged over a portion of the day as

$$\overline{f(z)} = \overline{i(z)} - \overline{h_t(z)},$$

where the overbar indicates the time average. Figure 3 shows the depth dependence of the terms of the heat balance averaged from 0400 h to 1400 h for the data of Figure 1 when the average mixed-layer depth, z_0 , was about 11.3 m. Two things are immediately evident: (a) below the mixed layer all terms in the heat budget are small compared to their values in the layer, and there is thus only a very small flux of heat out of the bottom of the mixed

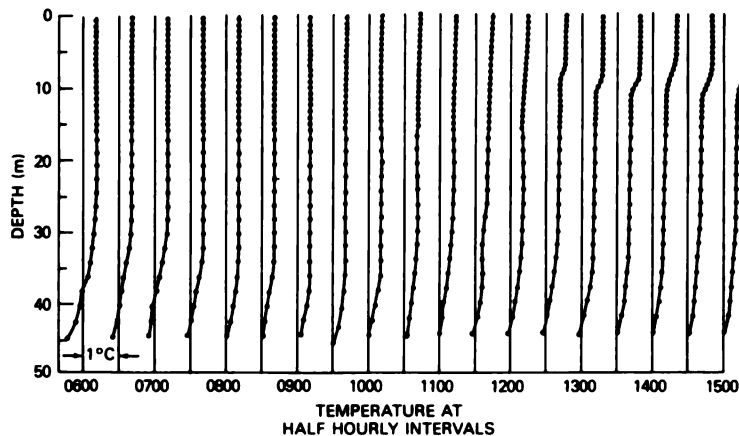


Figure 1. Upper ocean temperature profiles taken at 30-min intervals on Sept. 8, 1974 with a high-resolution temperature-pressure profiler. For each profile, temperature increases from left to right (1°C scale shown at lower left). By 1230 h, a 10-m deep warm mixed layer is forming and it becomes almost 0.5°C warmer than the water below by 1500 h. The vertical reference line locates 27°C for each profile.

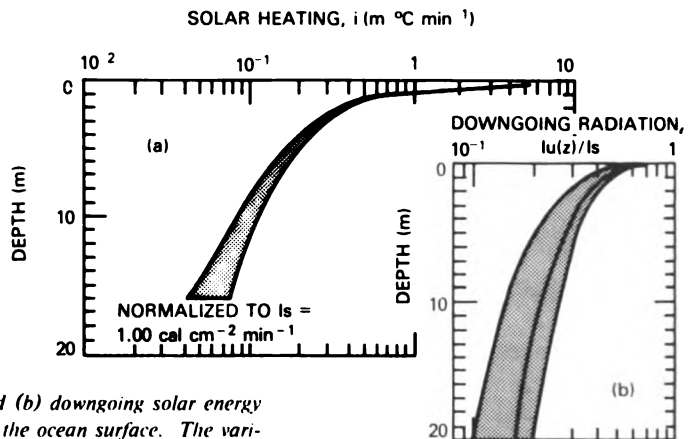


Figure 2. (a) Solar heating as a function of depth and (b) downgoing solar energy as a function of depth. Both are normalized to values at the ocean surface. The variation at a fixed depth is due to the cyclic change of solar elevation and the random variation in cloud cover.

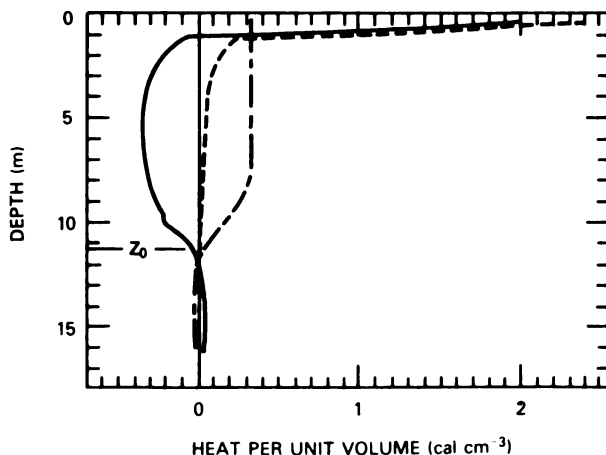


Figure 3. Terms of the heat balance to a depth of 18 m for data in Figure 1 averaged from 0600 h to 1400 h. Each curve is a per unit volume measurement of: solar heating -----, heat transported out by convection and advection —, and heat stored - - - -.

layer; and (b) there are two regions in the mixed layer, separated at a depth of about 1 m, where different balances occur. In the upper meter, the heat balance is $f(z) \sim -i(z)$, and below 1 m, $f(z) \sim -h_i(z)$. So, the upper ocean mixed layer can be decomposed into two regions which are governed by simplified thermal dynamics.

These conclusions allow several significant advances in understanding and probing the mixed layer. For instance, in calculating heat transfer in the upper ocean under the above conditions, the vertical heat flux can be neglected at the bottom of the mixed layer. Then the mixed layer can be treated essentially as a heat storage medium with an insulated bottom. To measure the amount of heat transported downward in the upper ocean, one need only measure the solar irradiance at the surface and at 1 m depth. This technique replaces a difficult heat flux measurement that requires an integration of thermal changes over the whole mixed layer with a relatively simple irradiance measurement.

[Sponsored by ONR]

Thermal Structure of Ocean Eddies and Fronts, by A. F. Schuetz and J. P. Dugan, *Ocean Sciences Division*

Six surveys, each involving five to seven ships, have been conducted over a 2-year period to measure mesoscale (30 to 1000 km) horizontal temperature variability in central regions of the North Atlantic and North Pacific Oceans. Each survey lasted about four days—a

period short enough in the ocean to make temporal changes negligible. Expendable temperature probes (XBTs) were dropped at 30-km intervals to map the thermal structure in the upper 800 m within rectangular areas of 30° longitude and 2° latitude. Numerous mesoscale features (eddies and fronts) were observed that could significantly affect underwater acoustic propagation as well as influence other environmental parameters.

One of these ocean features can be seen in Figure 4, a sequence of XBT temperature profiles taken through a warm eddy in the North Pacific in May 1976. This eddy has affected the depth of the mixed layer at the top of the ocean, as indicated by that portion of each profile exhibiting relatively constant temperature. The layer extends from almost zero depth outside the eddy down to over 300 m at its center.

This variability in thermal structure is evident at all depths for which temperatures were measured. The variations of temperature along a fixed-latitude track can be seen for example in Figure 5, in which all the XBTs from a single ship transiting across the North Atlantic are superimposed. Although the largest deviations occur at about 500 m, differences are still greater than 5°C at 800 m. This corresponds to a 23 m/s change in underwater sound speed at that depth, a change that can significantly alter the path of long range sound waves.

Figure 6 depicts three aspects of mesoscale variability for the area of the Atlantic

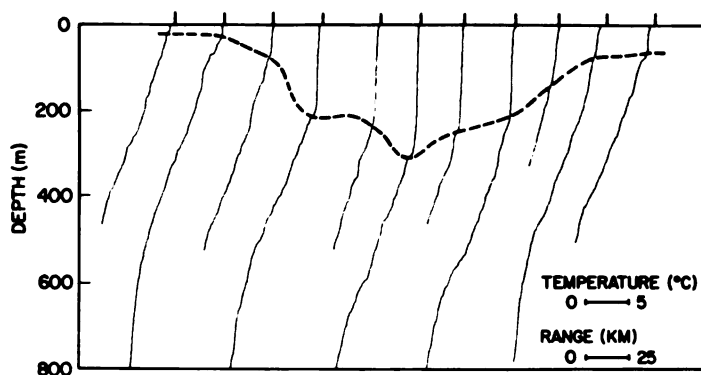
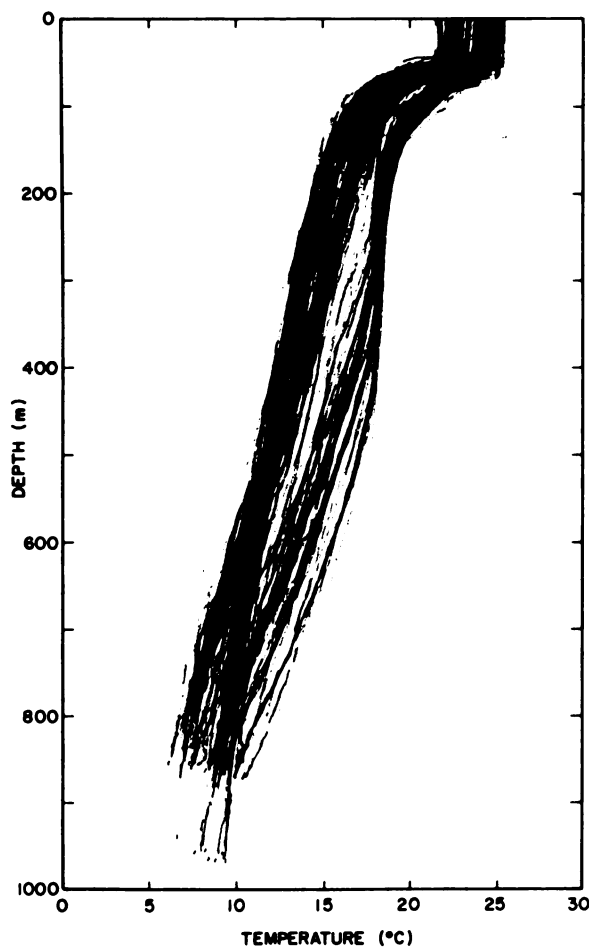


Figure 4. Sequence of XBT temperature profiles across an eddy in the North Pacific, May 1976. Broken line indicates depth of mixed layer. The horizontal scale is both location and temperature as shown. Each profile is shifted until its location mark (|) corresponds with 15°C .



Ocean bounded by 36–38°N and 30–60°W during May 1977. At the top is a contour plot of near surface temperatures (isotherms) that represents information that might be measured remotely (*i.e.*, orbital or airborne infrared imagery). The middle plot shows the depth contours in meters at which the 14°C temperature occurs. This map characterizes variability below the seasonal mixed layer near the surface and reaches down into a region known as the main or permanent thermocline. Finally, the bottom plot in Figure 6 shows a vertical temperature section derived from XBTs dropped from the ship transiting the center latitude of the survey area. Points of equal temperature are connected to form isothermal lines and the 14°C isotherm is emphasized to show the relationship with the map above.

A front near the Mid Atlantic Ridge at 41°W bounds the eastern Sargasso Sea from the colder eastern Atlantic upper ocean waters. This feature is most evident in the temperature section (Figure 6). Eddies are distinguishable from fronts by closed contours, as found at

Figure 5. Superimposed XBTs measured from USS PEN-SACOLA, October 1977 along a 36°40'N track in the North Atlantic extending from 30°W to 60°W

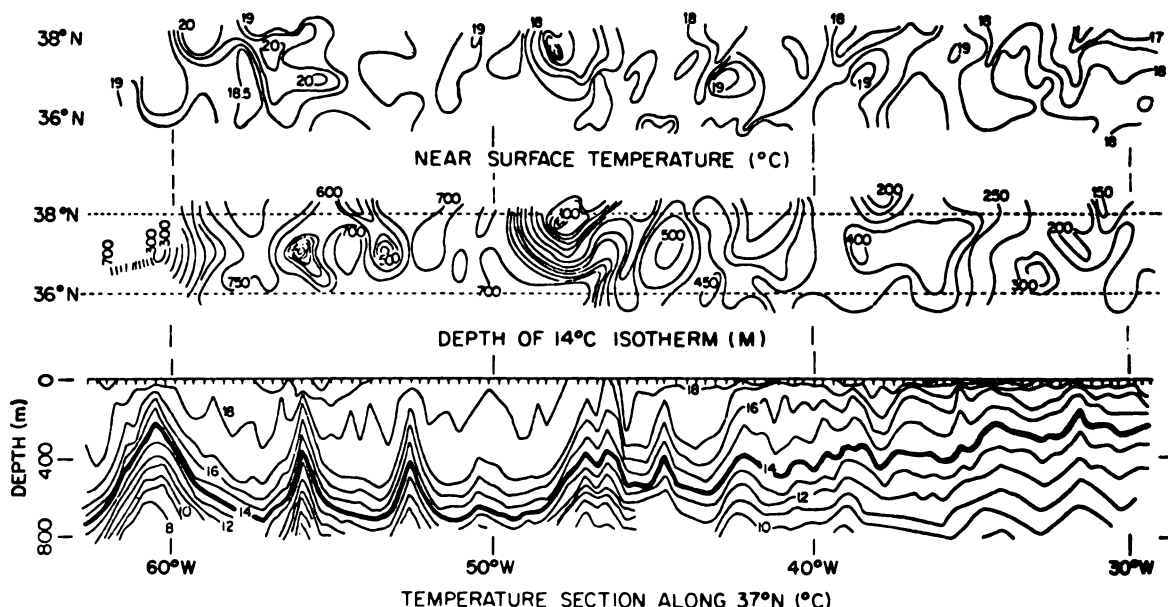


Figure 6. Mesoscale variability for the area of the North Atlantic bounded by 36–38°N and 30–60°W during May 1977. The three plots are: a contour map of surface isotherms (top); a contour map of the 14°C isotherm depth (middle); and a vertical section showing isothermal lines vs depth along track of ship transiting middle of area (bottom). Temperature cross section is based on uncorrected position data causing misalignment with mapped features above it.

44°W, 48°W, 53°W, 57°W, and possibly 61°W in the map of the 14°C isotherm in Figure 6. These features cause excursions of up to 600 m in the depth of that isotherm.

Since these eddies and fronts can greatly alter mid- to long-range acoustic propagation paths, they need to be considered in assessing the performance of underwater surveillance systems. And, more economical methods to detect and track these dynamic features need to be explored and developed.

It is important to note that, although some of the eddies can be detected in the near-surface temperature map of Figure 6, others cannot, and thus may go undetected by remote platforms using current technology. One alternative now under study involves an improved airborne XBT capability which could greatly reduce the time and resources necessary to obtain data of the required scale and resolution. These data would not only enhance immediate strategic surveillance capabilities but could also lead to a much needed, comprehensive statistical model of the seasonal and geographic distribution of these mesoscale features and, eventually, to a better understanding of their origins and links to other oceanic features and processes.

[Sponsored by ONR]

Global Monitoring of Ocean Petroleum Pollution, by W. D. Garrett, *Ocean Sciences Division*

NRL personnel are currently providing guidance to a global marine monitoring project for petroleum pollution operated by two United Nations agencies: the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the World Meteorological Organization (WMO). Acting as the United States representative to a scientific steering committee for this project, an NRL scientist has recommended improvements to the sampling methodologies for petroleum, has written guidelines for the visual distinction between oil slicks and natural surface films, and has participated in evaluations of the data collected by the participating nations.

Visual observation of oil slicks at sea proved to be one of the most valuable parameters determined by the monitoring project. Observational data have been processed in a computer-compatible form and presented in various displays such as Figure 7, which shows the percentage of positive observations of oil for 5-deg squares in the North Atlantic Ocean and adjacent regional seas. Other computer-generated maps produced from the collected data show that petroleum slicks are found predominately along shipping routes in the Mediterranean, the English Channel, the southern North Sea, the Caribbean, and in portions

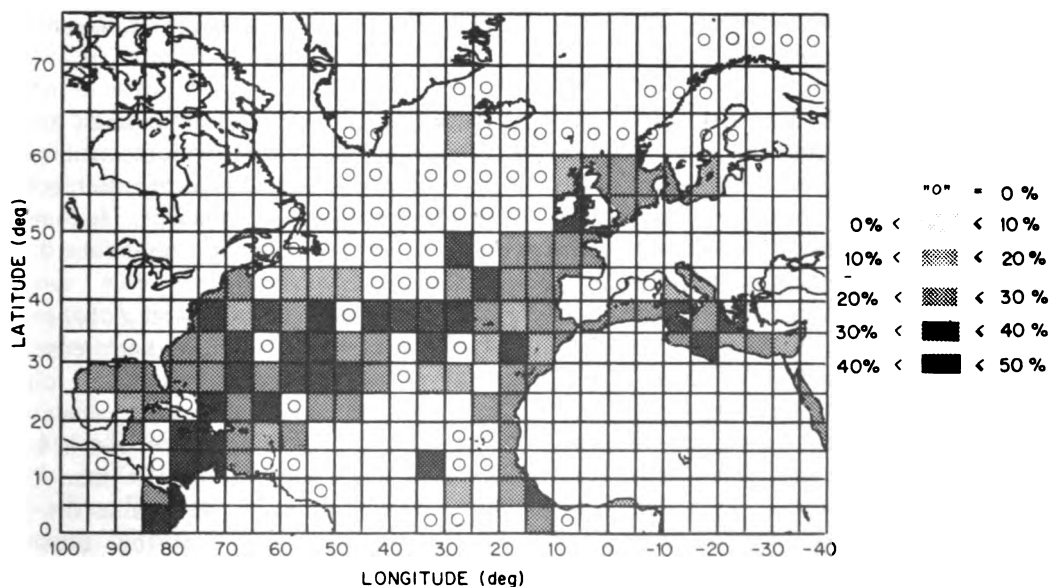


Figure 7. Visual observations of oil slicks reported under IOC-WMO-sponsored Marine Pollution Monitoring Pilot Project. Percentage equals number of oil reports divided by total reports for each 5-deg square.

Table 1
Oil Spill Detection by Remote Sensing

Sensor Approach	Spectral Region	False Signal Sources ^a
Active Reflectance	Microwave Radar, 1.5-5 cm	Natural organic slicks Wind slicks, ship wakes Pollutant organic slicks (detergents, sewage sludge) Kelp/debris Dense cloud cells Unrippled water under calm conditions
Passive Reflectance	UV, < 0.4 μm	Natural organic slicks Suspended solids
	Visible, 0.4-0.65 μm	Natural organic slicks Pollutant organic slicks Suspended solids Shallow water Broken cloud deck
	Near IR, > 0.65 μm	Natural organic slicks Other pollutant slicks
Passive Emission	Thermal IR, 3-14 μm	Natural organic slicks Pollutant organic slicks Ship wakes Thermal discharges and effluents Upwelling
	Microwave, 0.2-1 cm	Foam patches Kelp/debris Dense cloud cells

^aAll of the listed sensors detect oil on water, and natural petroleum seeps are therefore false targets for each of them.

of the Gulf of Mexico, the Red Sea, the Gulf of Aden and the South China Sea.

Information provided by this global monitoring project is important not only to the inter-governmental management of pollution from ships, but also to the scientific community because of the numerous impacts of oil on the marine environment. One such area of interest is the influence of petroleum slicks on the physics and chemistry of the air-sea interface. The pollutant films affect material transport between sea and air, the properties and dynamics of the air-sea interface itself, and the absorption and reflection of electromagnetic radiation. For example, oil slicks diminish the height of small waves, inhibit wave breaking, alter sea surface temperature, and modify the persistence and

bursting characteristics of air bubbles and foam at the sea surface. Furthermore, oil on the sea may influence the exchange of other pollutants by dissolving oil-soluble species, (such as pesticides) and by slowing physical transport processes.

The possible regional and global impact of petroleum pollution requires knowledge of the extent of sea surface coverage by oil films. Consequently, additional data analyses are being conducted by NRL scientists, in conjunction with personnel of the German Oceanographic Data Center, to determine the percentage surface coverage of the oceans and regional seas by oil and to produce an estimate of the quantities of oil present. A United Nations working group chaired by an NRL

scientist is using this information to ascertain the impact of oil on physical processes in the marine environment.

Another important by-product of the data from the monitoring project relates to the field of remote sensing. Sensors borne on satellites and on aircraft are used for studies of oceanographic properties and for following man's activities at sea. Oil films can be detected across a broad spectral range by both active and passive remote sensing systems. However, there are occasional events at the sea surface or between it and the sensor that may lead to incorrect signal interpretation. Table 1 reviews the types of sources that various sensors may falsely identify as petroleum slicks at sea. Both natural surface films and other pollutants may be incorrectly identified as petroleum by remote sensing devices.

In most instances, the true condition of the sea surface must be known if remotely sensed data are to be correctly interpreted. For example, the backscatter of microwave radar signals may be affected by any of the following events at the sea surface which diminish capillary waves: (a) zones of calm where no surface film is necessarily involved; (b) hydrodynamic damping in the wake of a ship; (c) wind slicks; (d) natural sea slicks caused by organic films which attenuate capillary waves and resist their formation; and (e) thicker layers of wave-damping petroleum oils or other organic film-forming pollutants. The other sensors in Table 1 used for the detection of oil on water also are subject to a number of possible false signal sources. Conversely, sensor response to oil films may be confused with other information being sought by remote sensing systems. Thus it is essential to identify the ocean regions where oil spills are prevalent so that possible interference with the interpretation of the remotely sensed signals can be considered.

[Sponsored by ONR]

Marine Aerosol Distributions and Their Optical Effects, by G. L. Trusty and T. H. Cosden, *Optical Sciences Division*

Because of the many operational advantages that devices utilizing visible and infrared wavelengths offer, the Navy is considering the deployment of a number of electro-optical

instruments for shipboard use. Many of these anticipated advantages emerge only in a free-space environment. Unfortunately, the marine environment is quite different from free-space. Electromagnetic waves propagating through the marine atmosphere encounter many impediments which include turbulence in the atmosphere that causes a defocusing of optical beams, molecules that absorb energy from these beams, and aerosols that scatter energy away from the intended target. Fortunately, the effects of atmospheric turbulence at sea are relatively insignificant and, while molecular absorption can be severe, it is quite well understood and computer modeling can predict its effects with a high degree of accuracy. However, the effects of atmospheric aerosols can be quite severe, are not well understood, and have not been adequately modeled.

NRL scientists are working on the problem of the atmospheric aerosol and its effects on propagating light beams. To calculate the extinction coefficient due to an aerosol, it is necessary to know the particle size distribution of that aerosol. This is not a simple problem because the atmospheric aerosol is a highly complex system that includes hail, snow, rain, clouds, fog, haze, dust, smoke, and permanently suspended particles. These components occur in a considerable range of sizes from several centimeters (hail) to nanometers (permanently suspended particles). However, the range of interest can be reduced considerably by ignoring those large particles which seldom occur (e.g., rain, hail, and snow) and those which are so small that they are not efficient light scatterers (i.e., with radii smaller than about 10% of the wavelength of the impinging light). Thus, the effective range of interest includes particles with radii from 0.1 to 150 μm . Three particle spectrometers are used in the NRL program to cover the entire size range.

The experimental counting and sizing of aerosol particles is done optically to avoid disturbing the sample. Two of the instruments detect the smaller sizes by measuring the size of a pulse of light scattered from each particle as it passes by. Particles larger than 10 μm are measured by the shadow each particle casts on a linear photodiode array (the number of photodiodes occulted gives the particle size.)



Figure 8. The VAN vehicle for aerosol numeration

This system was developed with two primary requirements: (a) that the results be immediately available for comparison with optical transmission measurements, and (b) that the entire operation be highly mobile. To accomplish these, the particle counters were interfaced with a minicomputer and mounted, with appropriate meteorological instrumentation, in a converted motor home vehicle. Figure 8 shows the VAN (Vehicle for Aerosol Numeration) at a fog measurement site at Otis AFB, Mass., in May 1978. The particle probes are the three larger white instruments on the roof.

During measurements, the minicomputer produces plots of particle size distributions similar to those in Figure 9, which shows particle size distribution ($\text{cm}^{-3} \mu\text{m}^{-1}$) vs particle radius (μm). These samples show the significant changes in distribution that can occur within periods of a few hours.

The minicomputer was also used to calculate the predicted extinction coefficients for the measured aerosol at various wavelengths of interest. For example, in July 1978, the equipment was removed from the VAN and installed on board the ADMIRAL FITZROY, a British

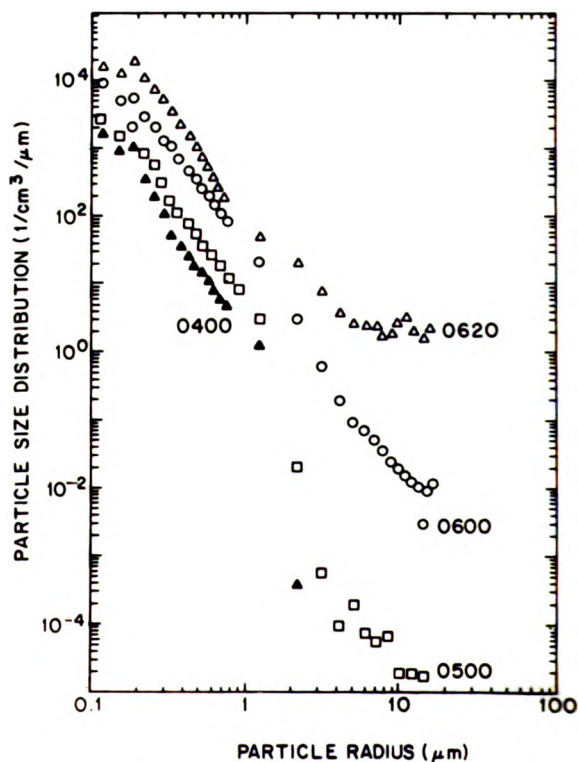


Figure 9. Atmospheric aerosol samples showing variation in size distribution at San Clemente, Calif., Sept. 9, 1977 during 140 min of early morning fog development

ocean weather ship. At one North Atlantic site in July, we obtained more than 200 20-min averages of aerosol distributions, and real-time calculations of the predicted extinction coefficients for ten wavelengths were made from each set. The examples plotted in Figure 10 illustrate the enormous variations that can occur.

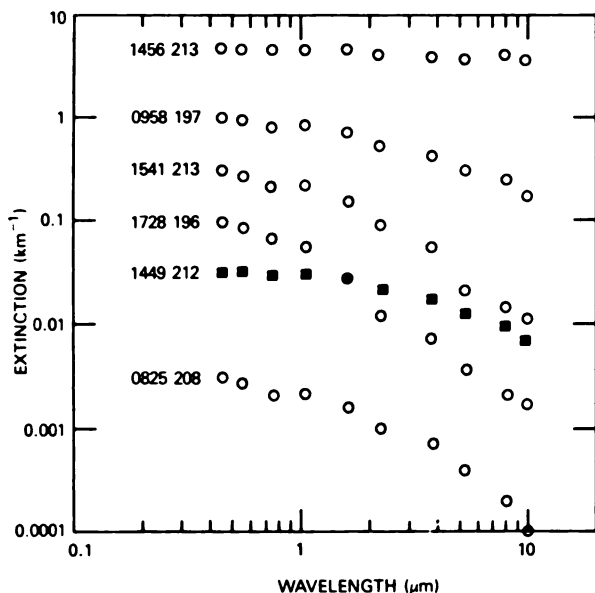


Figure 10. Extinction due to aerosol calculated from size distributions measured in the North Atlantic environment showing enormous variations that can occur. (The time and the day of the measurement are given to the left of the data points.)

At this point, the first stage of this aerosol investigation is essentially completed. The mobile system for monitoring aerosol size distributions has been assembled and used to make measurements in many locations. The VAN is the most advanced system in existence for measurements of this kind and has enabled us to accumulate what is probably the largest collection of aerosol data available pertaining to optical wavelengths.

Further investigations will include at least three problems: (a) measurement of the effective index of refraction of the particles *in situ*, (b) remote measurement (e.g., hundreds of meters off board) of the aerosol size distributions, and (c) the measurements and calculations for nonspherical particles. The first two

problems will be addressed in the coming year—the third is less tractable and longer range.

[Sponsored by NAVSEASYS COM]

Attenuation of Light by Marine Aerosol Particles, by H. Gerber, *Ocean Sciences Division*

Light passing through the atmosphere is attenuated by aerosol particles in two ways; a portion of the light's energy is absorbed by the particles, and another portion is scattered into new directions. Those effects are important for several reasons: scattering reduces atmospheric visual range; both effects degrade the performance of optical weapon systems; and their ratio influences the temperature of the atmosphere. There are some concerns that temperature changes induced by man-produced aerosols are causing climatic change. Presently, little is known about the attenuation of light over the oceans that cover 70% of the Earth. That is because transmissometers, which are instruments used to measure the attenuation, are impractical to use at sea because they require a firm baseline of about 1 km. The light absorption properties of aerosol particles are also poorly known because of uncertainties in existing experimental techniques. As a result, it has been impossible to determine whether man's contribution to the atmospheric aerosol content causes climatic heating or cooling.

Scientists at NRL have developed a new instrument (Figure 11) that has improved the art of measuring both the attenuation and the absorption of light by aerosols. The attenuation is measured by passing a collimated light beam from a laser through a cell filled with aerosol. A total beam path length of 20 m is accommodated in a 2-m cell by folding the beam with mirrors placed at each end of the cell. The result is an instrument that is sufficiently compact to be used on a ship. The use of the 20-m path length, instead of the 1-km length required for transmissometers, demands significant improvements in measurement resolution and accuracy. Several factors contribute to achieving this: (a) Openings on a mechanical chopper are arranged so that the sensor is alternately illuminated by the portion of the laser beam transmitted through the cell, and by a reference portion obtained with a beam

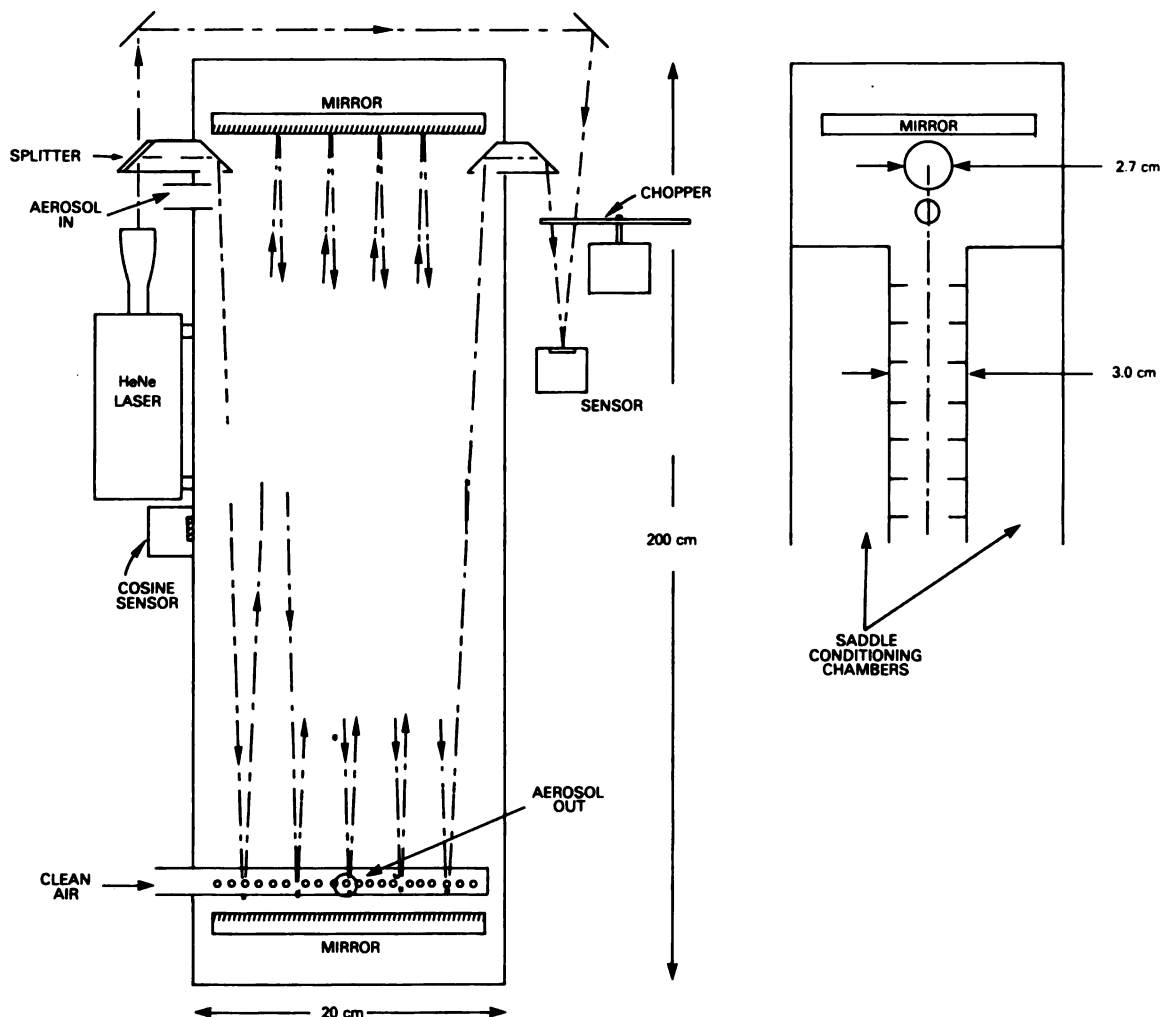


Figure 11. Schematic front view section of the aerosol cell (left) showing the laser-beam paths (— · — · —), optical components, and aerosol ports. Clean air flushed over the lower mirror reduces unwanted particle deposition. Side view section (right) shows light baffles lining the optical path and outer conditioning chambers through which air is passed rapidly to assure near-ambient temperature in the inner chamber where the optical measurements are made.

splitter located near the laser. With some additional electronics, the sensor gives a relative attenuation measurement independent of any error introduced by drift in laser output and sensor response. (b) Filtered air is introduced into the cell between attenuation measurements to permit subtracting such influences as contaminated mirrors. (c) Ambient aerosol is centrifugally concentrated before its introduction into the cell to enhance attenuation. (d) Speed and flow rate are carefully monitored to avoid dispersion errors.

The laser light scattered by the aerosol particles in the cell is measured with a second

sensor mounted in the side of the cell. The sensor has an angular response proportional to the cosine of the angles at which light is scattered and gives the particles' scattering coefficient as its output. The simultaneous measurement of attenuation and scattering in the same aerosol volume constitutes the new method of determining the particles' absorption coefficient. The absorption is simply the attenuation minus the scattering.

The value of the new instrument in a marine environment was demonstrated by measurements of particle absorption and scattering made during a recent cruise of USNS

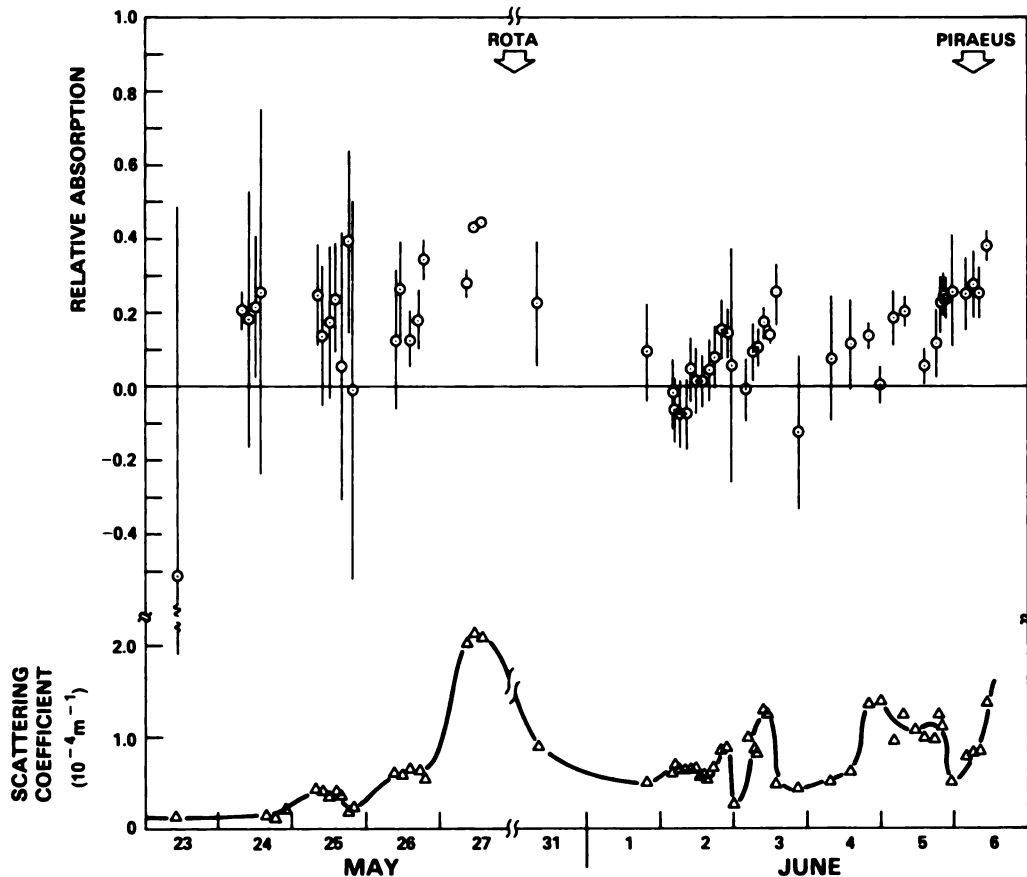


Figure 12. Optical properties of marine aerosol measured as USNS HAYES sailed eastward from near the Azores to Rota, Spain, and then continued eastward through the Mediterranean to Piraeus, Greece. Vertical lines on absorption points represent 80% confidence limits.

HAYES. Figure 12 shows several significant features in the data collected as the ship sailed eastward from the vicinity of the Azores to Rota, Spain, and then on to Piraeus, Greece in the Mediterranean. On approaching Europe, the turbidity of the atmosphere grew as shown by the increases in aerosol scattering and absorption. Maximum values were found near landfall at Rota and Piraeus. A likely explanation for the unexpectedly high absorption of light is the presence of a large fraction of carbonaceous particles in the marine atmosphere. Since such particles are formed by burning fossil fuels, their origin would be in populated continental areas.

This modification of marine aerosols by man's activities must be known both for the operation of naval electro-optical systems and for input to models that predict climate. Additional measurements in different geographical

areas are planned in order to assess the impact of marine aerosols on a global basis.

[Sponsored by NOSC]

Effects of Organic Material on Cloud and Fog Processes, by W. D. Garrett, W. R. Barger, and S. G. Gathman, *Ocean Sciences Division*

Fundamental studies by NRL investigators and others have demonstrated that organic surfactants (surface-active substances) may cause a wide variety of effects on clouds, fog, and rain. These effects are attributed to the ability of the surfactants to form films one molecule thick at an air-water interface. When water drops in air are coated with such organic films, they can be made to grow more slowly, resist coalescence, oscillate, disintegrate, and evaporate more slowly or even more rapidly than clean water. These effects depend upon

the chemical nature of the polar organics involved, their concentrations at the air-droplet interface, whether films formed from them are free to flow rapidly enough to modify a particular cloud process, or whether the organic material can alter the activity of nuclei on which cloud droplets grow.

Because of these manifold possibilities, researchers have postulated a wide variety of potentially useful modifications of atmospheric processes which might be produced by introducing film-forming surface-active material into clouds and fog. These potential modifications include rainfall enhancement; stabilization, prevention and dispersal of fog; inhibition of nucleation; alteration of cloud dynamics, *etc.* Thus, NRL scientists perceived a need to critically examine the role of both natural and additive organic substances on phenomena that govern the weather in order to answer the following questions: Do natural organic surface films play a significant role in cloud processes? Can man modify clouds, fog, and rainfall in useful ways by introducing certain organic, film-forming materials into the atmosphere?

The influence of organic surface films on cloud processes was assessed through a review of pertinent information which included recent NRL research on the characteristics of atmospheric organic constituents (Table 2). It was concluded that natural organic material will not greatly influence condensation nucleation, drop growth, or drop evaporation in the atmosphere.

Although it is possible that partial surface film coverage by natural material may lead to dynamic instability in airborne drops or inhibit water drop coalescence, there is no scientific evidence that these effects occur in nature. The question marks in the table indicate that effects are possible but completely unproved, and (-) signifies that no organic influence is possible based on the conclusions developed in the NRL review of current knowledge.

Neither natural nor additive man-made films have been shown to halt the growth of water drops on condensation nuclei, even under ideal laboratory conditions. The vapor condensation rate can be slowed at the air-water interface, but it is extremely difficult to completely deactivate all hydrophilic and/or hygroscopic sites on an irregularly shaped atmospheric particle by deposition of a closely packed organic layer over the entire particle surface.

Finally, Table 2 shows a review of the potential for useful weather modification by intentionally introducing film-forming organic substances into the atmosphere. Partial coverage with organic films may affect the dynamic stability and internal flow of the drop, but will not act as a vapor barrier. The impact of partial films has been inferred from laboratory results, but no conclusive studies have been made of such effects in the atmosphere. The condensational drop growth on hygroscopic particles may be somewhat retarded under conditions of low humidity. Condensed films of linear organic

Table 2
Influence of Natural and Intentionally Added Organic Surface Films on Cloud Processes

Surface Film		Nucleation Inhibition	Condensation Retardation	Evaporation Retardation	Coalescence Barrier	Modification of Drop Dynamics
Natural		—	—	—	?	?
Additive	Complete Coverage	—	+	++	?	+
	Partial Coverage	—	—	—	—	+

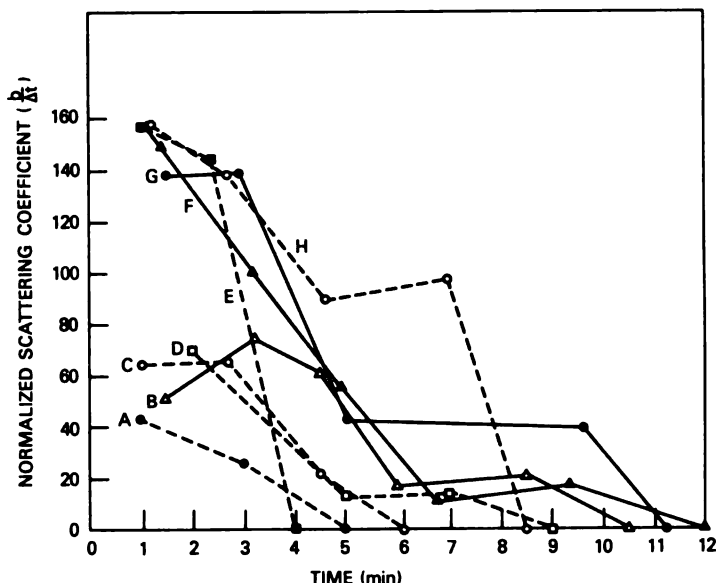
— Influence unlikely.

+ Demonstrated in laboratory; field studies, if any, were inconclusive.

++ Effect demonstrated by laboratory and field research.

? Potential influence, but not proved by experiment.

Figure 13. Light scattering vs time for eight artificially generated plumes of water droplets as observed by aircraft-mounted instrument. Treated superdroplets (solid lines B, F, G) persisted at least 1½ min longer than normal water droplets (dashed lines A, C, D, E, H). Data normalized to elapsed time of instrument in plume.



molecules have been shown to retard drop growth, evaporation, and stability in numerous laboratory studies. Inhibition of fog-drop evaporation and growth by condensation has been demonstrated in large-scale chamber and field experiments.

This analysis was intended to review the proposed mechanisms for cloud and fog alteration and to evaluate their potentialities objectively on the basis of existing knowledge. From this we concluded that natural film-forming substances are not expected to significantly affect the physics of clouds. In addition, although numerous approaches to weather modification with additive film-forming materials have been postulated, only evaporation retardation of airborne drops has been clearly demonstrated in real-world studies. One example is a recent NRL field study conducted over the waters of Nantucket Sound in which plumes of water droplets, with and without man-made organic film coatings, were introduced into a moderately dry atmosphere with a relative humidity below 80%. The light scattering ability of these plumes is degraded by both turbulent diffusion and decreases in the droplet sizes by evaporation. The results (Figure 13) showed that, although all of the plumes were eventually dissipated by turbulent diffusion, the coated plumes, having droplets larger than the uncoated evaporating plumes, scattered light longer. Thus, if stabilized fogs have significant

visible and infrared extinction, they would be suitable for electrooptical screening applications.

[Sponsored by ONR and NAVAIRSYS-COM]

Real-Time Sea Spray Monitor, by D. J. Bresnan, *Ocean Sciences Division*

Responding to the need for a means of evaluating efficiencies of the air filters used on marine hovercraft turbine engines, NRL scientists have constructed a new, real-time sampling device to monitor the sea spray ingested by an air intake system. The design of this sea spray conductivity meter (SSCM) was based on the fog conductivity meter (FCM) described in NRL's 1975 Review. The SSCM development illustrates the transition from a basic research tool to an unattended instrument applicable to ship engineering and design.

The SSCM (like the FCM) draws a continuous stream of sample air through a set of fine-mesh filters. These meshes are known to collect approximately 97% of the wet spray in the sample stream. When sufficient spray has been collected to wet the screens, the collected liquid drains into a small, electrical-conductivity measuring cell. The conductivity is continuously recorded and indicates the rate of accumulation of spray water as well as its salt content. The spray samples are also retained for

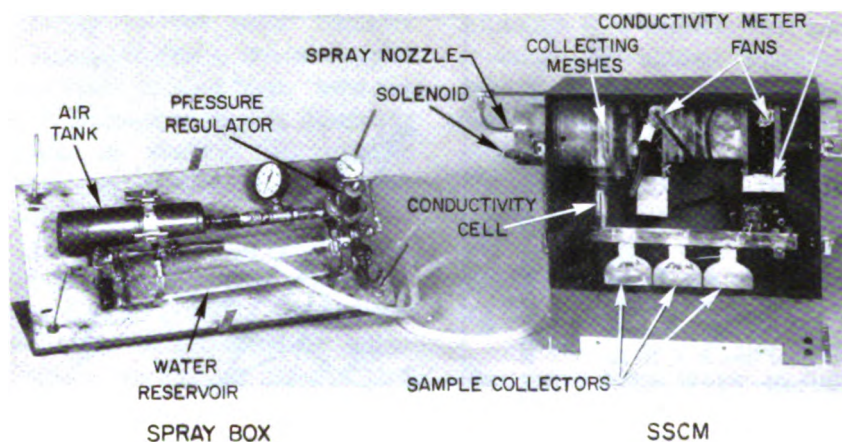


Figure 14. The sea spray conductivity meter (right) and its associated spray box (left) that allows controlled washing of the collecting meshes

later chemical analysis. Figure 14 shows the SSCM with its associated spray box attachment (discussed below).

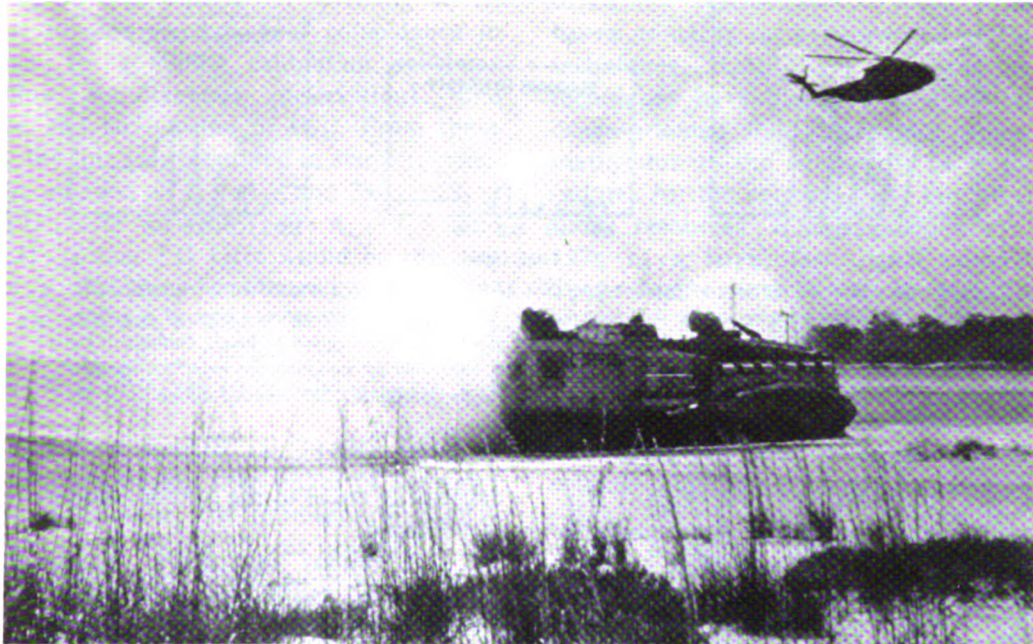
The SSCM samples at $1 \text{ m}^3/\text{min}$, can be adjusted to perform at airstream velocities of 4.6 to 12 m/s, has a water flow rate of 90 ml/min in 5 ml increments, and measures salt concentrations in the air up to $3 \text{ g}/\text{m}^3$. It is housed in a box 18 by 41 by 43 cm, and draws 80 W of 60-cycle power.

Two versions of the SSCM successfully gathered data aboard the JEFF(B) (Figure 15) surface-effect craft in April, May, and July 1978. The first unit was designed for heavy spray loadings of up to 1000 ppm anticipated for the well-deck area of JEFF(B) and did not include a spray unit. During the April mission, short bursts of up to 200 ppm spray were indeed recorded and these contributed significantly to the mission average of 0.7 ppm. During the May mission, however, there were no spray events that had enough water content to drain into the conductivity cell. Salt residue did accumulate on the meshes from small droplets collecting and evaporating there during the run, but no water drained into the cell for detection and measurement. To solve this problem the SSCM was equipped with the remotely triggered spray attachment for the July missions. This permitted periodic washing of the meshes with known quantities of distilled water. This controlled washing arrangement allows measurement of the salt buildup on the

mesh, even in the absence of heavy spray events. Washings triggered by an on-board observer made it possible to determine the salt loadings associated with various spray events or ship maneuvers, as shown in Figure 16.

More recently, this device has been equipped with a timer to initiate spraying automatically after selectable intervals. This determines the average salt loading during the intervals. Manual operation of the sprayer or the collection of natural spray drop samples automatically resets the timer to begin a new interval. In this way, the time resolution for salt loading of the air might vary from about 6 s (for heavy natural sea spray) to the full length of a timed interval of 5, 10, 20, 40, or 60 min for dry aerosols.

The SSCM and spray box are mounted at the sampling location (Figure 15(b)), while the spray controller and strip chart recording units are remotely located in protected areas along with an observer. An automatic device such as this can be further refined into a better basic research tool, that continuously monitors the salt load in the marine atmosphere, in either wet or dry form, over a period of several days. Aerosol sampling devices currently available for chemical use can collect either droplets or dry aerosols. The NRL device is the first one to accommodate both wet and dry aerosols, present a real-time readout, and retain the sample solution for later analysis; all without the necessity of operator assistance.



(a)

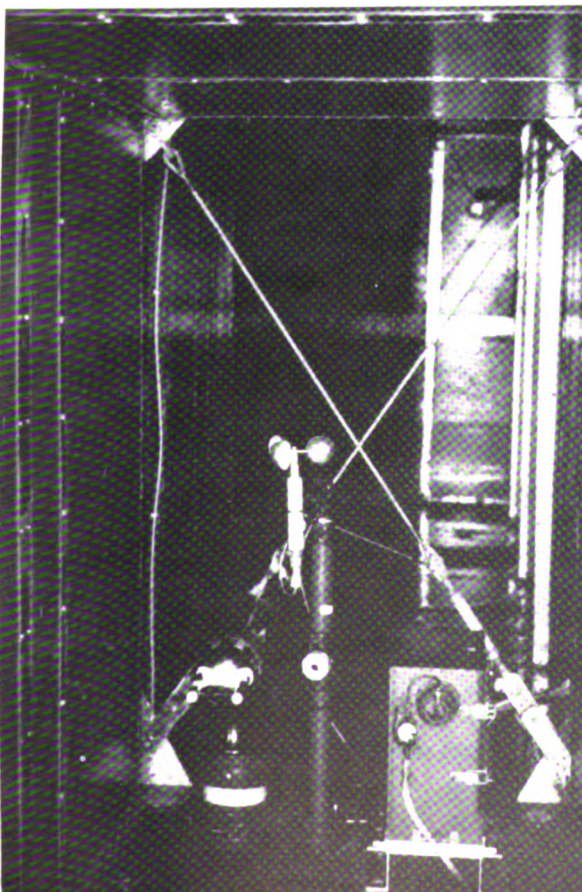


Figure 15. (a) JEFF(B) hovercraft generates sea spray as it encroaches beach (left to right). (b) SSCM (lower right) mounted in the JEFF(B) inlet system, beside a wind vane and particle size spectrometer. Inlet faces open well-deck area partially enclosed by engine housing in portion of landing craft obscured by spray in Figure 15(a).

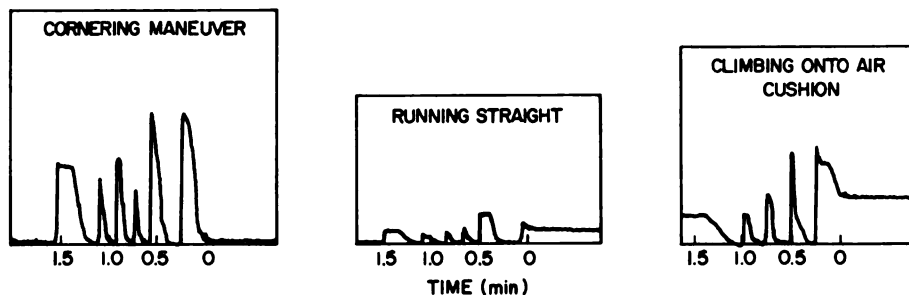


Figure 16. Selected portions of readout from SSCM on July 13, 1979 aboard hovercraft JEFF(B). Each straight vertical drop on the stripchart indicates delivery of observer-initiated washing of collecting meshes into collection bottle. Salt concentration of each delivery is given by height (salinity in log units) of subsequent peak. The total salt and water, estimated by summing the stripchart records, agreed to within 10% of that actually recovered in the collection bottle. Salt ingested during cornering maneuver was roughly $10 \times$ that during straight run.

We are planning a three-stage, size-discriminating device capable of simultaneously recording atmospheric salt loads while continually collecting time-integrated samples for each size range. With real-time recording, the separate retention of each sequential sample in each of the size ranges planned would allow improved chemical and physical interpretation. This would facilitate not only turbine corrosion studies but basic research into the physics and chemistry of marine aerosols.

[Sponsored by ONR and NAVSEASYS-COM]

Microwave Spectroscopy of the Atmosphere, by P. R. Schwartz, *Space Science Division*

Passive microwave spectroscopy is a powerful technique for detecting and measuring minor atmospheric species, for mapping their altitude distributions, and for measuring the physical state of the middle atmosphere. As discussed in NRL's 1974 Review, emission and solar-induced absorption spectra of the atmosphere may be used to determine the altitude distribution of ozone (O_3), provided that the stratospheric temperature profile is known. Superficially, this proviso seems insignificant in view of existing remote-sensing methods for determining temperatures. But two factors must be considered. First, the temperature data should be temporally and spatially coincident, since the O_3 and temperature distributions are not independent. Second, the parameter of interest is the excitation temperature (T_{ex}) of the O_3 transition that produces an absorption or emission line, and T_{ex} is not

necessarily equal to the kinetic temperature that is measured.

To employ microwave spectroscopy for ground-based monitoring of O_3 , a method for obtaining T_{ex} is needed. Recent work at NRL, directed toward demonstrating the effectiveness of microwave spectroscopy as a worldwide O_3 monitor, has yielded a simple technique for estimating the excitation temperature. This technique requires only the proper selection of microwave O_3 transitions; T_{ex} is obtained from the measured intensities of pairs of absorption or emission lines. One line, say line 1, results from O_3 molecules making the transition from an initial state, say state 1, to state 1'; line 2 results from O_3 molecules making the transition from state 2 to state 2'. In the case of an optically thin, plane parallel isotropic atmosphere,

$$T_{ex} = \frac{\Theta_{12}}{\ln \left[A \frac{K_{2,2'}}{K_{1,1'}} \right]},$$

where Θ_{12} is the temperature equivalent of the energy difference between the initial states, $K_{1,1'}$ and $K_{2,2'}$ are the observed temperature-equivalent intensities of two transitions 1-1' and 2-2', and A is a constant which depends on the line strengths. T_{ex} may be used directly to infer total column density (number of O_3 molecules in a unit-cross-section column of atmosphere) from integrated intensity spectra. In addition, the expression for T_{ex} can be modified to a function of frequency shift from line center, and incorporated in line-shape-fitting analysis to obtain the O_3 altitude distribution (and the T_{ex} altitude profile).

The obvious criteria for selecting an O_3 line pair to observe are: near coincidence in frequency (to eliminate calibration problems and allow simultaneous observation), line strength, and large value of Θ_{12} . From these criteria, the line pair identified in standard spectroscopic notation as $4_{1,3}-4_{0,4}$ and $28_{5,23}-29_{4,26}$ near 102 GHz or the pair $8_{0,8}-7_{1,7}$ and $20_{4,16}-21_{3,19}$ near 125 GHz would be the best to observe. Facilities for observing these transitions are not yet available at NRL, but the line pair $15_{3,13}-16_{2,14}$ and $14_{2,12}-15_{1,15}$ near 30 GHz has been observed to test the adjacent-line technique.

Despite the fact that the 30-GHz lines are about 40 times weaker than either of the more favorable transitions, the atmospheric absorption spectrum in Figure 17 was obtained at the NRL Maryland Point Observatory with 5-MHz spectral resolution. Analysis of the data from this pair of transitions yields an effective O_3 excitation temperature T_{ex} of 211 ± 7 K in the altitude range 25 to 45 m.

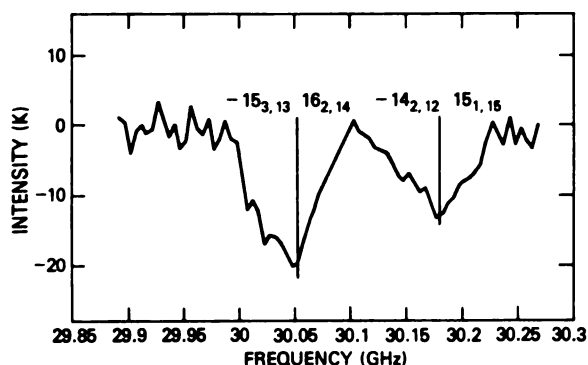


Figure 17. Atmospheric absorption of solar radiation in two adjacent O_3 lines near 30 GHz. The temperature equivalent of the energy difference, Θ_{12} , of the two lines is 33 K.

These preliminary experiments have demonstrated the utility of the adjacent-line technique for O_3 measurements. In 1979 it will be incorporated into a series of O_3 -monitoring experiments.

[Sponsored by ONR]

Numerical Simulation of Ocean Waves, by E. W. Miner, *Ocean Technology Division*

During the past decade, NRL has been increasingly involved in ocean-oriented fluid

mechanics research. This research has been based primarily on experimental and analytical techniques. Until very recently, numerical techniques have played only a minor role in ocean-oriented fluid mechanics research, primarily due to the complexity of solution procedures for the equations and limited computational resources. The acquisition by NRL in 1976 of a large, fast digital computer (the Texas Instruments Advanced Scientific Computer or ASC) increased the computational resources available to laboratory personnel. Meanwhile, researchers in other areas of fluid mechanics had made considerable progress in developing improved numerical procedures for solving complex equations. In particular, algorithms were becoming available for solving elliptic equations such as those for surface waves on a liquid. Thus it was possible for numerical techniques to play an increased role in ocean-oriented fluid mechanics research.

The present research is based on a computational code, SPLISH, developed by J. P. Boris and M. J. Fritts at NRL. This code has two significant features that make it particularly suitable for the numerical calculation of progressive surface waves: the triangular mesh and the Lagrangian formulation of the governing equations. Successful first steps in the numerical simulation of ocean waves have been achieved.

A first case for consideration is a two-dimensional wave channel of constant depth, much like the NRL wave-wind channel. The amounts of central memory on the ASC and computing time required are both significantly reduced by the imposition of periodic boundary conditions, which require left side and right side conditions to be equal. Wave calculations are thus restricted to an integral number of wavelengths. For the constant-depth channel, numerical simulation of one wavelength is usually sufficient.

The grid for one wavelength of a progressive surface wave in a constant-depth channel is illustrated in Figure 18. An advantage of the triangular grid and Lagrangian approach is clear in this figure. Triangle vertices function as markers for fluid particles, and their motion tracks the flow of the fluid. The free surface forms the upper boundary of the computational domain and is well defined by the triangle sides

if the grid size is sufficiently small. One approximate measure of the validity of the numerical simulation results is the shape of the surface profile. The profile shown in Figure 18 agrees well with classical wave theory.

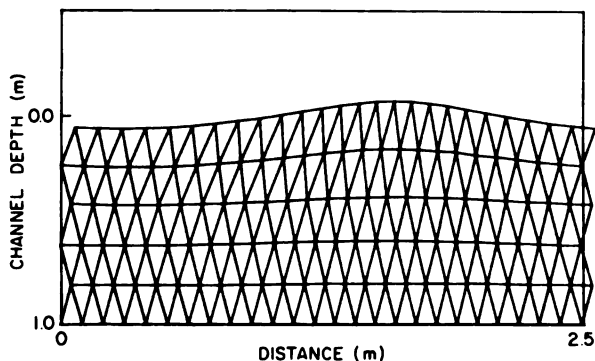


Figure 18. Computer simulation of wave flow in constant-depth channel. Wave crest has progressed from left to right in 41 incremental steps at a simulated speed of 1.92 m per s.

A more demanding measure of the simulation validity is given by the calculated paths of individual fluid particles. Figure 19 shows the paths of a surface particle and a particle 0.2 m below the surface for a channel depth of 1 m. These paths agree reasonably well with those calculated from classical, nonlinear wave theory, as do the wave parameters.

A more difficult case for wave simulation is wave flow over an obstacle on the channel

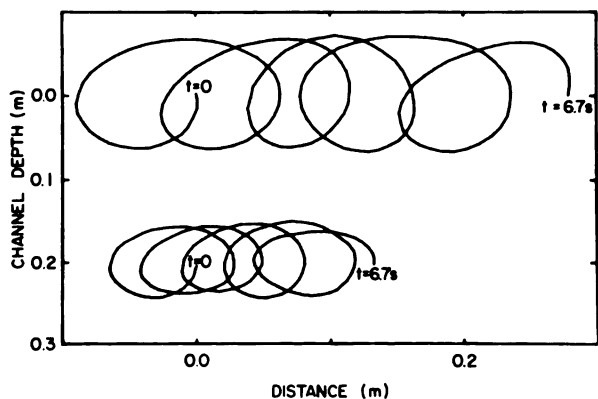


Figure 19. Particle drift paths by numerical simulation for a wave of 1.34-s period, 2.5-m length in 1-m deep channel. Time (t) is shown at start and finish of simulated path. Drift and wave period compares well with nonlinear wave theory of Stokes.

bottom. A half-cylinder would be representative of a half-buried pipe and, with the periodic boundary conditions, would represent one element of a regular array of pipes. Such a situation is shown in Figure 20. Results thus far for this case have been encouraging but have not been as satisfactory as for the constant-depth channel case. The complexity that the half-cylinder adds to the problem has been a driving force in making improvements to the simulation method. Critical factors thus far have been grid size, or proportioning, and time step size in the integration of the time-dependent equations.

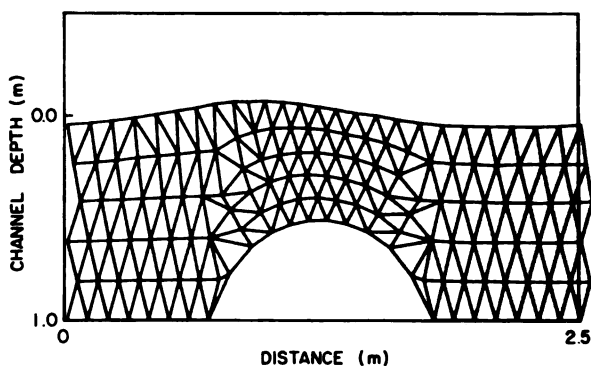


Figure 20. Computer simulation of wave flow over half-cylinder. Wave crest has progressed from left to right in 31 increments at a simulated speed of 1.92 m per s.

Several factors are expected to control the direction of future work. More rapid solution procedures need to be implemented to reduce computing time and cost. Improved techniques for forming the grid are needed to give better resolution in critical areas of the computational domain without over-resolving other, less critical areas. This would also reduce computing time and cost. Techniques for control of integration errors can be very significant in the numerical simulation and need to be improved. More flexible boundary conditions need to be developed, as the present periodic conditions are overly restrictive. Also, the present techniques for initiating the progressive wave need some refinement. Satisfactory progress in these areas for the present two-dimensional case would justify work on a three-dimensional approach, a future goal of this study.

[Sponsored by ONR]

Current-Induced Forces on Ocean Structures, by O. M. Griffin, *Ocean Technology Division*

It is often found that bluff, or unstreamlined, structures undergo damaging oscillatory instabilities due to the actions of winds and currents. The most common cause of these resonant, flow-excited oscillations is the organized and periodic shedding of vortices as the flow separates from opposite sides of a long, bluff structure in some alternating fashion. The shedding vortices exhibit a dominant periodicity, and the structure experiences time-dependent pressure loads. These loads result in steady and unsteady drag forces aligned with the flow, and unsteady lift or side forces in the cross flow direction. If the structure is flexible and lightly damped, then these forces can excite resonant oscillations both normal and parallel to the incident flow. For the more common cross flow oscillations, the structure and the vortices have the same frequency (near one of the natural frequencies of the structure) and the vortex shedding is shifted away from the flow-generated, or Strouhal, frequency at which pairs of vortices would be shed if the structure were stationary.

When a cylindrical structure vibrates laterally to an incident flow, the periodic motion is accompanied by more regular shedding of the vortices axially along the structure and an amplification of the steady and unsteady flow-induced forces. The typical vortex-excited resonant responses of three cylinders in water are shown in Figure 21. Though the fluid forces have been measured by several investigators, only recently have studies been made of the mechanisms by which these fluid-structural interaction forces are generated. In one such study just completed at NRL, the fluid forces induced on a resonantly vibrating, cylindrical structure by vortex shedding have been characterized. The various force components are:

- the exciting force, by which energy is transferred to the structure;
- the reaction, or damping, force which is exactly out-of-phase with the structure's velocity;
- the "added mass," which is exactly out-of-phase with the structure's acceleration; and
- the fluid inertia force.

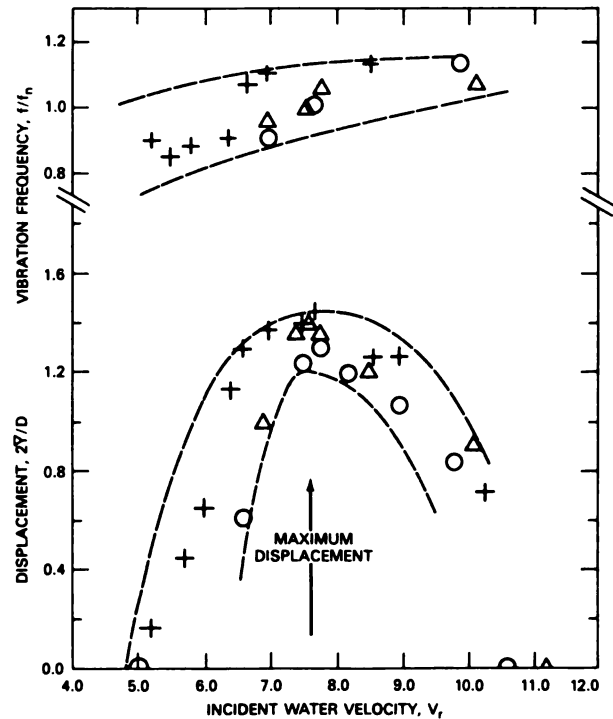


Figure 21. Vortex-excited displacement amplitude $2\bar{Y}$ of three cylinders in water (measured in multiples of the cylinder diameter D) and vibration frequency (scaled by the natural frequency f_n) plotted as a function of the reduced velocity $V_r = V/f_n D$, where V is the incident flow velocity. The three cylinders had length/diameter ratios between $L/D = 8$ and 15 , natural frequencies between $f_n = 1.3$ and 2.4 Hz, and specific gravities of 4.8 . Dashed lines mark boundaries of experimental data.

These components can be deduced by Fourier analysis from the total hydrodynamic force or they can be measured individually.

The exciting force is characterized by the coefficient $C_{LE} = C_L \sin \phi$, where ϕ is the angle between the lift coefficient, C_L , and the displacement of the structure. This component of the force system is important because it transfers energy from the flow to the structure. It has been measured by both of the methods just mentioned, and the results for three types of cylindrical structures (Figure 22) show several important characteristics of the lift and pressure forces that accompany vortex-excited oscillations. First, each case shows a maximum in the exciting force at peak-to-peak displacements between 0.6 and 1 diameters. Second, the maximum of the force coefficient is approximately $C_{LE} = 0.5$ to 0.6 for most cases, a sin-

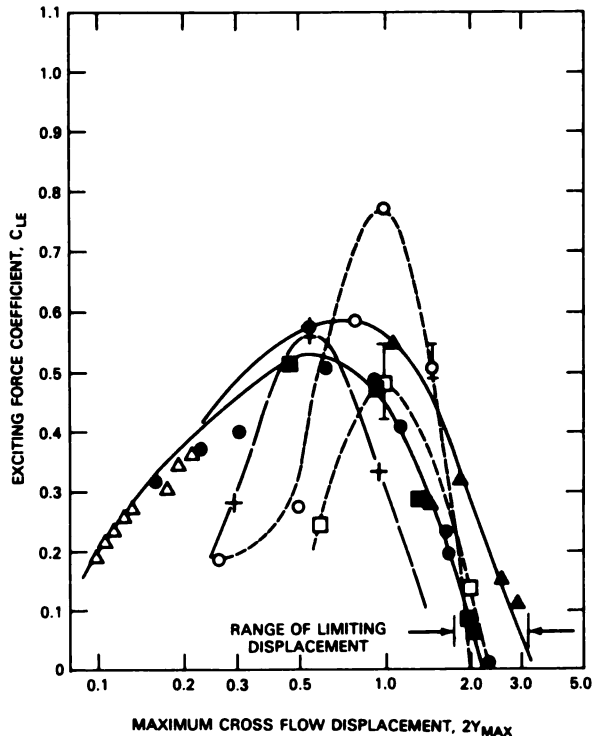


Figure 22. The exciting force coefficient C_{LE} (the actual force divided by $(1/2) \rho V^2 D$, where ρ is the fluid density) plotted against the maximum cross flow displacement $2Y_{MAX}$ ($Y = \bar{Y}/D$). Data were obtained from measurements in flowing air and water on forced oscillating rigid cylinders, shown by the symbols $\circ$, $\square$; spring-mounted rigid cylinders excited by vortex shedding, shown by the symbol $+$; and cantilevered flexible cylinders in the fundamental mode of oscillation (all other symbols). The range of limiting displacements for structures with vanishingly small damping is shown in the figure.

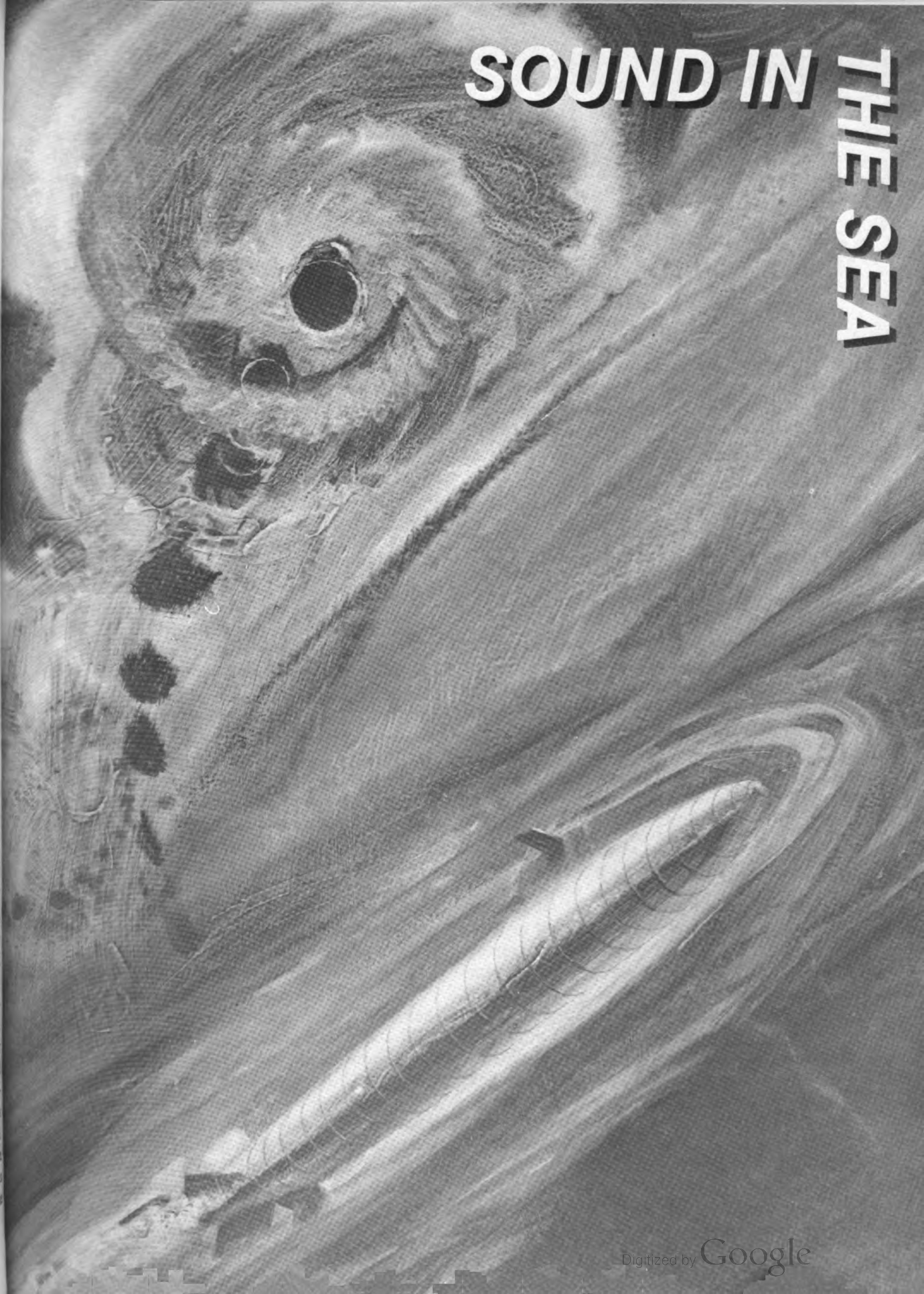
gle exception being one measurement $C_{LE} = 0.75$. Third, C_{LE} decreases with increasing displacement until energy transfer ceases at a limiting effective displacement of between 2 and 3 diameters.

Vortex-excited oscillations not only amplify the unsteady exciting forces but they also increase the steady drag loads substantially. Steady drag coefficients as high as $C_D = 3.1$ have been measured on a cylindrical structure vibrating in water at a displacement of $2Y_{MAX} = 1.7$. This is nearly three times the drag on the stationary cylinder. In wind tunnel measurements at NRL, the drag coefficient on one of the vibrating cylinders shown in Figure 22 was almost twice that measured in the corresponding experiment with the cylinder held stationary.

Problems associated with the shedding of vortices have been neglected in the design of offshore structures, largely because reliable experimental data and design methods have been unavailable. However, the dynamic analysis of ocean structures has become increasingly important with the need to predict stress distributions and fatigue life in harsh environments. Reliable experimental data are now in hand for the dynamic response of and flow-induced forces on model-scale structures, and have provided the basis upon which new prediction models have been developed and calibrated. However, prototype and full-scale test data are essential before predicting the effects of vortex shedding can become state-of-the-art for the design of ocean structures.

[Sponsored by NAVFACENGCOM]

SOUND IN THE SEA



SOUND IN THE SEA

Man's ability to "see" for significant distances through water depends on his ability to project and detect sound in the water. For the Navy, such vision is vital and must continually improve in clarity, range, and precision as submarines go deeper, faster, and quieter and remain longer on station. Ever since the formation of the original underwater acoustics unit that was a part of NRL's beginnings in 1923, the Laboratory has maintained a continuing and productive interest in this important area.

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Acoustic High-Gradient Experiment, by W. A. Kinney, W. B. Moseley, and J. S. Perkins, *Acoustics Division*

Ocean fronts such as the Gulf Stream form laterally extensive, horizontal sound-speed gradients. They are the strongest members of a wide class of dynamic ocean features whose influence is growing because of an increasing awareness of their extensiveness and because of their importance in limiting the performance of underwater acoustic surveillance systems.

To measure precisely the effects of fronts on acoustic array performance and the vertical distribution of acoustic energy, an oceanographic-acoustic study was conducted during April 1978. The study involved propagation paths from the cold waters of the continental slope off Norfolk, Virginia, eastward through the Gulf Stream into the warm Sargasso Sea. This region was chosen for the following reasons: (a) the Gulf Stream is among the strongest fronts in the world and therefore provides a good test of modeling and measuring capability; (b) the front was stable in the chosen location; (c) the propagation paths provided for deep, long-range transmission; and (d) the area was logistically convenient. In this acoustic high-gradient experiment, numerous measurements were made with the source-receiver dispositions shown in Figure 1(a). Two recoverable, deep-moored, constant-frequency sound sources were deployed; one at 224 Hz, 300 m depth, on the cold side of the front (S₁) and one at 230 Hz, 1000 m depth, on the warm side (S₂). The receiver was the Versatile Experimental Kevlar Array (VEKA), a linear array of 32 hydrophones spaced at 10-m intervals. The VEKA was deployed vertically, and measurements were made with the array at a 1500-m center depth at several locations, one of which (R) is shown in Figure 1(a).

When the experiment was designed, archival sound-speed and bathymetric data (Figures 1(b),(c)) were used to model propagation both through and outside the front. The results of this modeling were used in selecting the experimental geometry. Figure 2 shows predicted acoustic intensity and angle of arrival (measured vertically from zero at the horizontal plane) as a function of range from the source. Intensity is indicated by the darkness of the trace and light to dark spans a 30-dB range. In

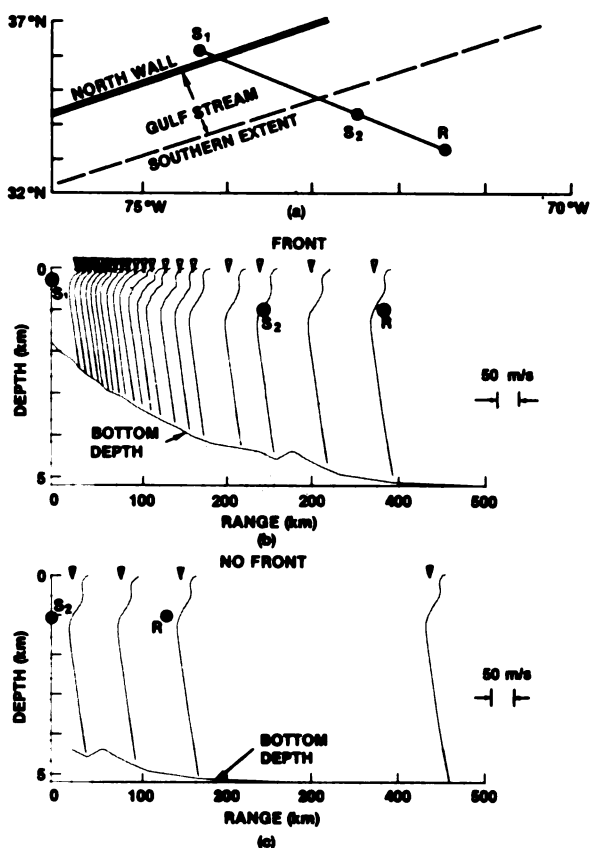


Figure 1. (a) Experimental geometry showing locations of sources (S₁ and S₂) and receiving array deployment (R). (b) and (c) Cross-sectional archival sound-speed and bathymetric data used to model acoustic propagation from S₁ through the Gulf Stream and from S₂ outside the stream. Darts across tops of (b) and (c) are reference points indicating range locations of the sound-speed vs depth profiles. Each profile is positioned so that the dart also points to its 1500-m/s value (sound speed increases from left to right for each profile).

this model the source depths are the same as used in the experiment, and likewise, the array center depth is 1500 m. In Figure 2(a) the modeled energy propagates through the front (corresponding to Figure 1(b)), and in Figure 2(b) it propagates through a similar region without a front (corresponding to Figure 1(c)). The model results showed in the first case that energy is concentrated in angle near the horizontal, but in the second (with no front) it is more distributed and bundled around two separate arrival angles.

The predicted qualitative difference between the two cases is evident in measured data from the experiment. Figure 3 shows acoustic intensity and angle of arrival measured

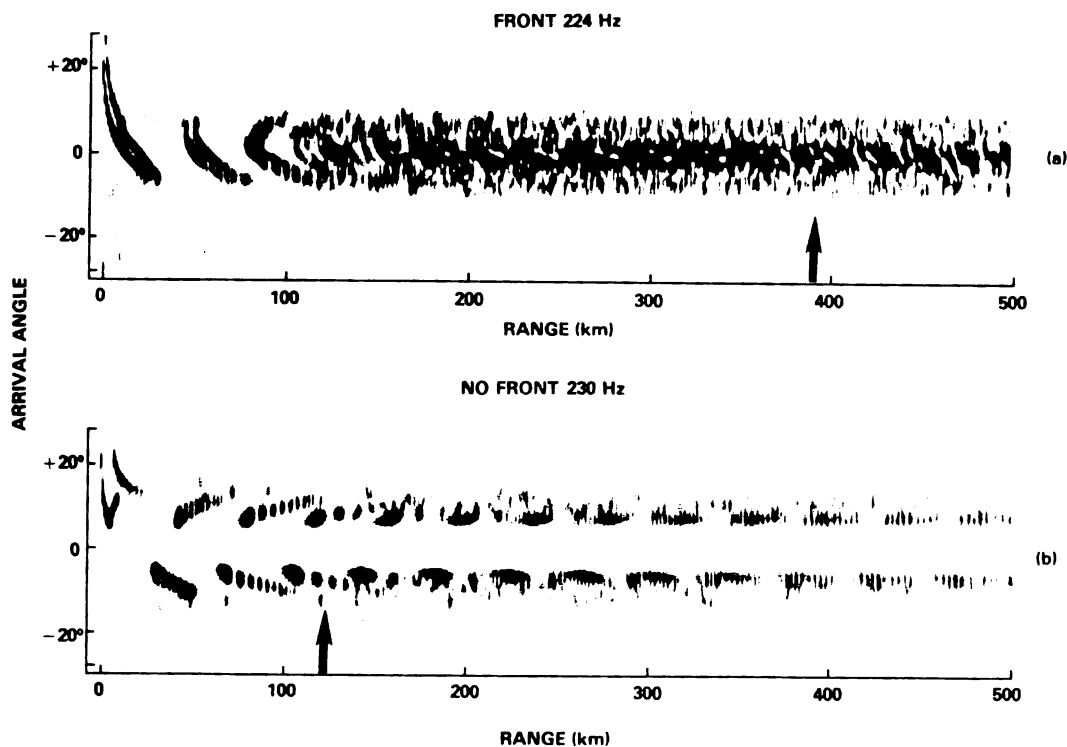


Figure 2. Predicted acoustic intensity vs range from source and vertical arrival angle of wavefronts relative to horizontal (positive is upward) for propagation (a) through the front from S1 and (b) not through the front from S2. Intensity increases with trace darkness and covers a 30-dB range. Arrows indicate ranges for equivalent at-sea data shown in Figure 3.

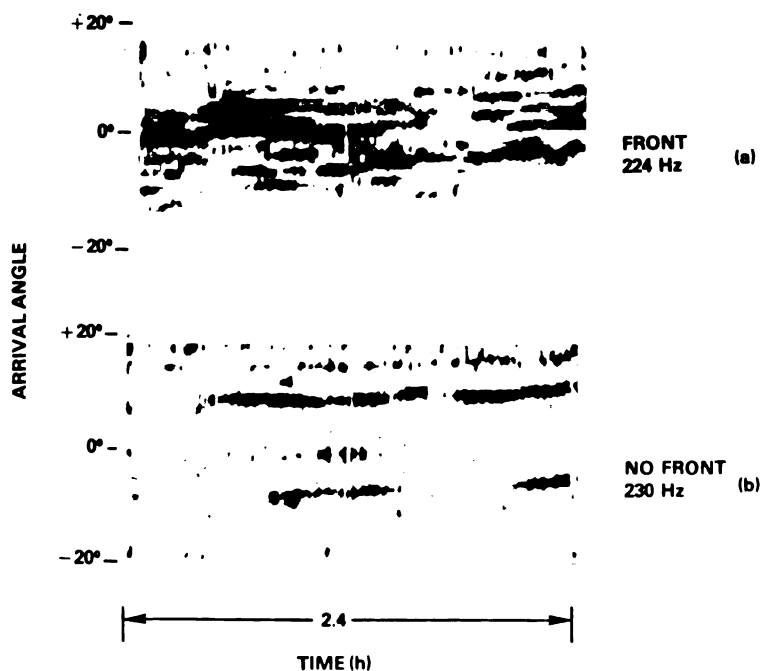


Figure 3. Measured intensity at R vs vertical arrival angle and time for propagation (a) through the front (from S1; range 390 km), and (b) not through the front (from S2; range 120 km). The slight drift in arrival angles was caused by array motion.

for a 2.4-h period by the VEKA array at location R. With propagation through the front (Figure 3(a)), a large number of acoustic arrivals were concentrated in the angular region near horizontal. Without the front (Figure 3(b)), the energy appears to have arrived in two distinct, well-separated angular arrivals. The model predictions at the corresponding ranges (indicated by arrows in Figure 2) are in good qualitative agreement with the measured results.

The understanding of such refractive effects by ocean fronts and other environmental anomalies will contribute to more effective design and use of arrays in underwater surveillance. In the coming year, we will perform more precise modeling and analysis of frontal influences using sound-speed and bathymetric data collected during the experiment.

[Sponsored by NAVMAT and ONR]

Sound Propagation Modeling with a Realistic Ocean Bottom, by C. W. Votaw and G. R. Giellis, *Acoustics Division*

The development of sonar-performance prediction models requires a mathematical representation of the decrease in acoustic level with range from the source. This decrease in level, or propagation loss, depends on the paths along which the sound spreads out and on energy losses at the ocean surface and bottom. In many ocean areas where long range sound propagation involves repeated bottom reflections, it is essential to recognize that each bottom reflection may introduce a horizontal change to the direction of propagation. This deflection is due to the slope of the bottom across the initial path of propagation. A set of such bottom-reflecting rays may become entwined and tangled in such a way that it is difficult to evaluate the propagation loss. One of the important terms in the propagation loss is the energy absorbed at each bottom reflection. This can generally be expressed as a function of the frequency and the grazing angle. The grazing angle can be easily calculated when the shape of the bottom is known.

In the NRL model, the bottom shape is expressed as a matrix of depth values on a square grid with a mesh size of 1 km, where two triangular subelements form each square.

Figure 4 shows such a projection of the sea bed in the Norwegian Sea. This patch is 350 km $\times$ 335 km and has a vertical exaggeration of 5 to 1. The bottom depth at an arbitrary horizontal location can be determined as lying on the triangular facet defined by three grid points.

Any sound ray striking one of these planar facets would be reflected specularly, and the bottom reflection loss would be calculated as a function of the grazing angle. In general, the reflection loss increases with grazing angle and the change is most rapid in the range of 20° to 50°.

The horizontal deflection of each ray reflected off the bottom depends on the magnitude and orientation of the bottom slope and on the initial horizontal and vertical angles of the ray. Rays that leave the source within a few degrees of each other will usually become so tangled and entwined after bottom reflection that projecting them on a single plane produces a confusing illustration. The three 100 Hz acoustic rays shown in Figure 4 all started from Point A with the same bearing angle (northwest) but with different vertical angles. As the rays progress they are refracted by the variation of the sound speed with depth and they are specularly reflected at each encounter with the surface and the faceted bottom. The three rays travel in essentially the same horizontal direction in the deep water until they begin to bounce into the ridged area. Then the ray which initially had a 10° vertical angle acquires a very steep angle and accumulates 60 dB from bottom losses on arrival at Point B. When a ray has suffered such losses it usually is too weak to be of further interest and is terminated. The ray with 5° initial vertical angle does not experience a 60 dB bottom loss until arriving at Point C, but by then its horizontal direction of propagation has changed by 4°. The third ray, which began with a vertical angle of 0°, suffers the least bottom loss and although initially it had the least horizontal direction change, by the time it reaches Point D it has changed direction by 15° and accumulated bottom losses of 30 dB.

This brief example shows the importance of modeling techniques that are three dimensional. Propagation between two points in the center of a deep flat basin would not require three-dimensional calculations because few rays

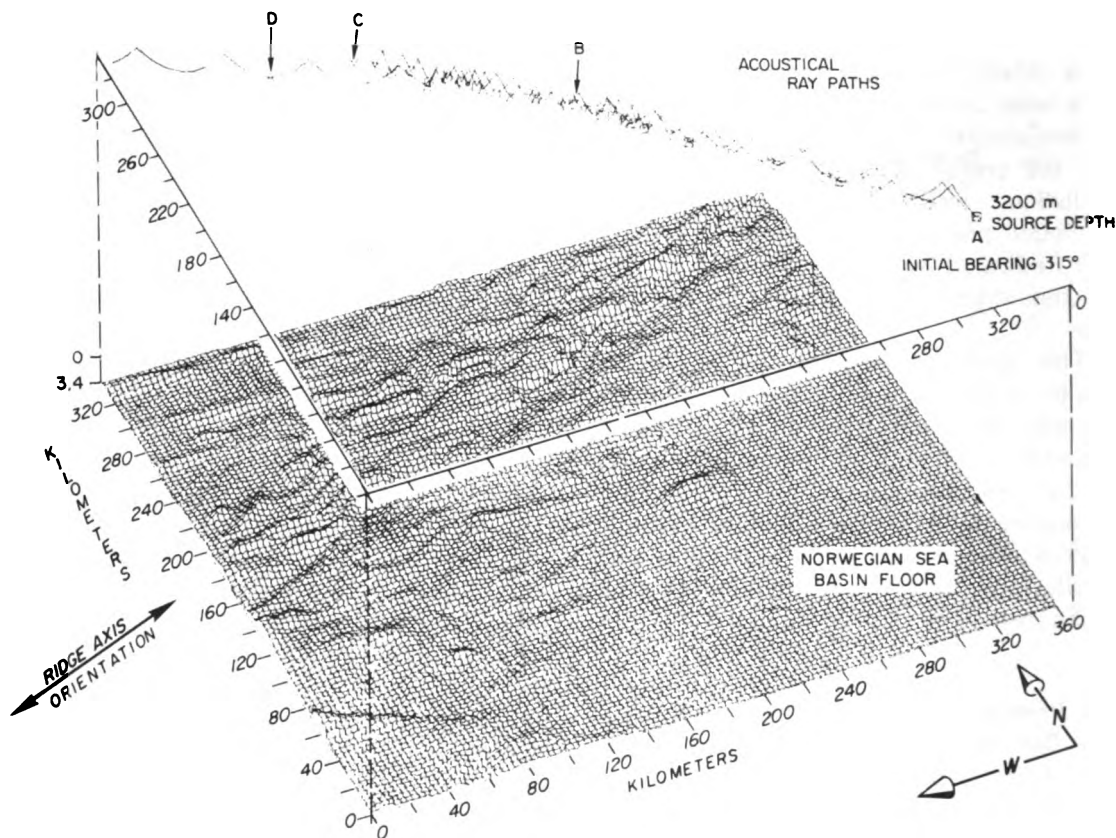


Figure 4. NRL computer-generated 3-D bottom grid for central portion of Norwegian Sea Basin. Acoustic ray traces are superimposed on exploded coordinates for clarity. Symbols identify each ray and locate bottom bounce along ray path. Initial ray vertical angles are: 10° ($\square$), 5° ($\circ$), and 0° or horizontal (Δ). Vertical exaggeration: 5 to 1.

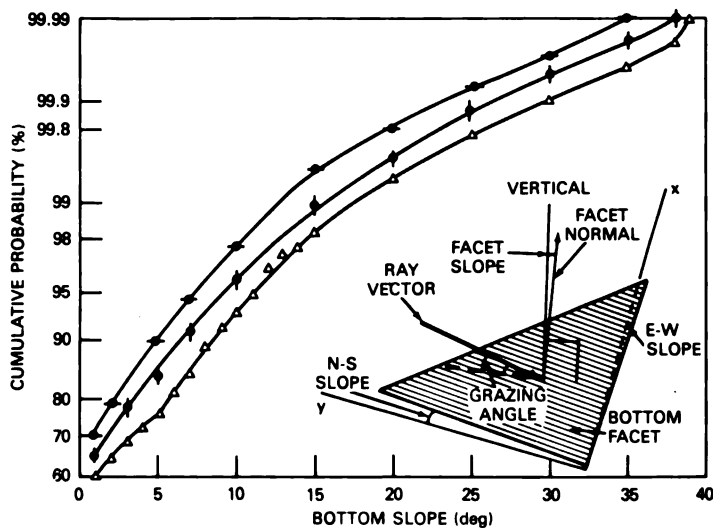


Figure 5. Distribution of Norwegian Sea Bottom Slopes ($\circ$ —E-W slopes, $\diamond$ —N-S slopes, Δ —Facet slopes) for region shown in Figure 4. Inset sketch diagrams method of calculating slope components of (shaded) bottom facet. Grazing angle is measured in plane passing through sound ray and line normal to facet.

would strike the bottom. Furthermore, since bottom slopes in such basins are almost all less than 1° , there would be little effect on the loss or the ray direction change. However, in rougher regions or where propagation over the whole basin must be considered, the rays that travel long distances would surely experience significant direction changes and losses during part of their travel.

In regions such as Mohn's Ridge (roughest part of Figure 4) the rays experience the most severe direction changes and may also experience their greatest losses. Since these effects are so closely related to the magnitude of the bottom slopes, the statistical distribution of bottom slopes has been measured for the patch modeled in Figure 4. Figure 5 shows the cumulative distribution of bottom slopes for the faceted bottom and also the components of that slope in the north-south and east-west directions. Although 60% of the bottom slopes are less than 1° , the 19% that exceed 6° are very significant for the three-dimensional ray tracing model.

The difference between the facet slopes and the component slopes shown in Figure 5 is an indication of the error that occurs if bottom slopes are determined from the bathymetric profile of a single ship track. These errors would be significant to the bottom loss calculations as well as to the determination of ray direction in more simplistic two-dimensional models.

Work is continuing to refine the three-dimensional model so that losses caused by spreading of the rays can be calculated and horizontal changes in sound speed can be included.

[Sponsored by Arctic Submarine Lab (NOSC)]

Nonlinear Pulse Propagation Studies, by P. H. Rogers and A. M. Weiner, *Underwater Sound Reference Detachment*

High-intensity signals generated by explosives and air guns can be transmitted for long distances underwater and through the many layers of sediment and rock found beneath the sea. Such sound signals are commonly used in acoustics research and seismic exploration and, as arrays of air guns, are also under consideration for active sonar systems. Before these

nonharmonic forms of acoustic energy can be developed for such systems, some better mathematical method of handling them and their nonlinear effects is needed. NRL has found that many such high-intensity sound pulses can be accurately modeled as an asymmetric, double exponential function—that is, as a wave whose pressure rises exponentially with one time constant and decays exponentially with a second time constant (see Figure 6). The surface-reflected shock wave and bubble pulse from an underwater explosion and the pressure pulse generated by an air gun are examples of asymmetric double exponentials. Although nonlinear effects are of little importance for the bubble pulse from an underwater explosion and the pressure pulse from a single air gun, they can cause significant energy, amplitude, and spectral changes in the water surface-reflected explosive shock wave or in the pressure pulse from an array of air guns.

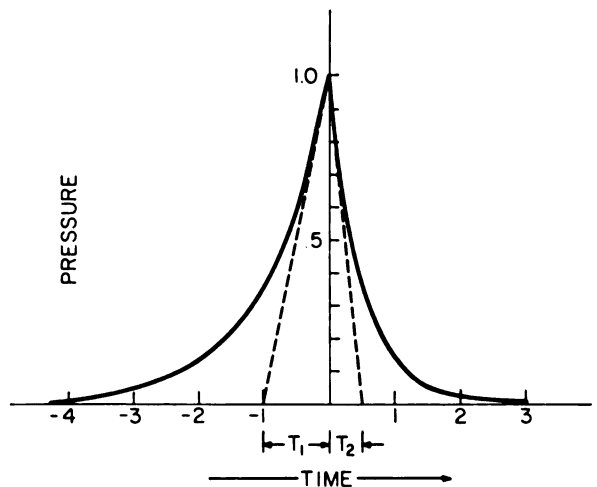


Figure 6. Asymmetric double exponential (mathematical) function with rise time T_1 and decay time T_2

The principle nonlinear propagation effect in underwater acoustic waves is the distortion of the waveform which arises from the variation of sound speed with amplitude. That is, the higher amplitude parts of a pressure wave propagate faster than the lower amplitude parts so that the peaks of the wave tend to overtake the troughs. This results in steepening much as one observes in gravity water waves as they approach the shore. Unlike gravity waves, however, acoustic waves cannot become multiple valued (and "break"); instead, when the

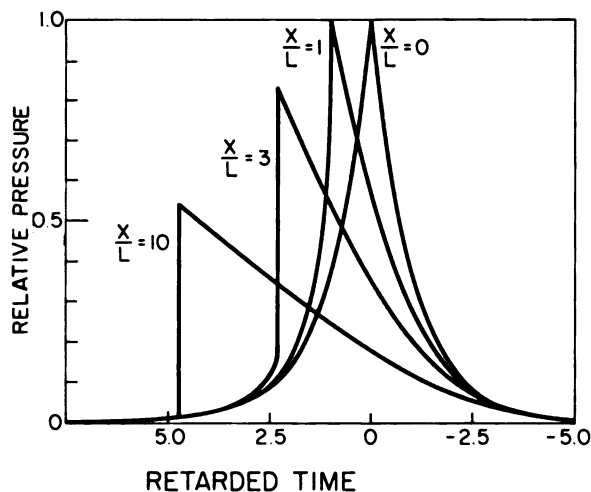


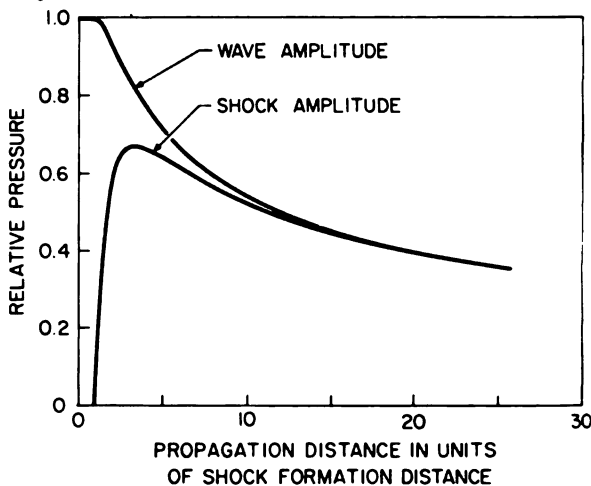
Figure 7. Distortion and attenuation of a "double exponential" sound pulse as it propagates

wave slope becomes infinite, a pressure discontinuity or shock forms. The shock front travels more slowly than the following sound wave so the overtaking process continues, but now at the expense of wave amplitude and energy. Unlike most waveforms that have been studied to date, the shock for a double exponential forms at the peak of the wave, so that wave attenuation and shock growth occur simultaneously.

NRL has developed a theory for modeling the nonlinear distortion and attenuation of a sound pulse that initially has the form of a double exponential. Simple closed-form results have been obtained for the wave amplitude and other parameters of interest to researchers contemplating the use of sound sources that produce intense signals of this kind.

A typical solution for the pressure waveform is shown in Figure 7. X/L is a measure of the distance from the source, and the initial waveform (at $X/L = 0$) was a symmetric double exponential. At $X/L = 1$, the slope of the wave becomes infinite to the left of the peak and a shock forms. At $X/L = 3$, the discontinuity (or shock) has grown but the amplitude of the wave has decreased. At $X/L = 10$, the amplitudes of the wave and the shock are both decreasing as the wave approaches the asymptotic limit of an N wave (that is a wave which rises discontinuously, then decays linearly). Note also that for $X/L > 0$ the peak of the wave arrives before the zero of retarded time ($t - x/c$) indicating that the pressure jump is propagating faster

Figure 8. Wave attenuation and shock growth followed by shock attenuation for a symmetric double exponential sound pulse



than the ordinary sound speed (c), yet slower than the overtaking nonlinear acoustic wave.

The amplitudes of the wave and shock as a function of X/L can be obtained by simple algebra for any double exponential. Figure 8 shows typical results for a symmetric double exponential. Note that the shock does not begin to grow and the wave amplitude does not begin to decay until $X/L \geq 1$. This is because energy can only be lost when a shock is present. The shock amplitude rises to a maximum at $X/L \approx 3.3$ and then asymptotically approaches the wave amplitude.

This study has developed the tools needed to examine a wide variety of problems involving the nonlinear propagation of acoustic transients. We hope to apply these results to the study of several problems of current Navy interest such as the calibration of explosive sources and the design and evaluation of air gun arrays. For example, our results indicate that an early surface reflection would add as much as 3 dB to the sound pressure level from an explosion, but that the formation of shocks may degrade the performance of air gun arrays currently proposed as active sonar systems.

[Sponsored by ONR]

A Unique Broadband Underwater Acoustic Source, by A. M. Young, *Underwater Sound Reference Detachment*

Underwater electroacoustic calibration measurements in open bodies of water are typically made at relatively shallow depths. To minimize the multipath effects of reflections from the surface and bottom, it is often desirable to use a calibration source that discriminates against those directions over the frequency range of interest; that is, a source that essentially confines the radiation within a beam relatively narrow in the vertical plane. Measurements can also be simplified if the output of the source is constant over the frequency range for which it is to be used. However, these two requirements are, in general, contradictory.

One transducer configuration which does show promise in meeting both requirements is the biconical linear array of piezoelectric ceramic rings shown in Figure 9. The cylindrical elements have a common axis and are arranged symmetrically with respect to the array center according to the frequency of their radial resonance. In other words, the array has the lowest frequency (largest) elements at the ends, with elements increasing in resonant frequency (decreasing in size) symmetrically toward the array center. The electroacoustic characteristics of such an array are determined by the number and relative sizes of the individual piezoelectric elements. When the elements are properly chosen and driven electrically in parallel, the array will provide a constant output level (sound pressure per volt) over the design frequency range. It will have a toroidal spatial distribution of sound energy with the axis of the

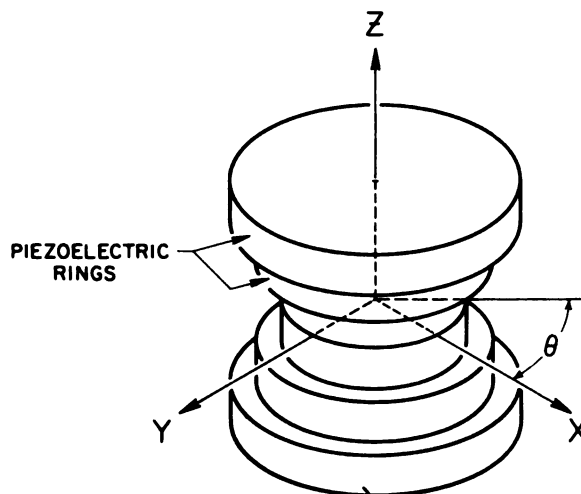


Figure 9. Biconical array of piezoelectric ceramic rings

toroid coincident with the longitudinal axis of the array.

To determine the element requirements, a generalized model of a linear array of piezoelectric ceramic rings was developed in terms of the physical constants of the piezoelectric material and the diffraction constants, radial resonance frequencies, and relative phases of the radiation from the individual elements. The calculations indicated by the model are performed by a digital computer in an iterative procedure to determine the element requirements for a given frequency range.

As a test of its validity, the model was used to design a four-element array for operation in the frequency range from 15 to 30 kHz. The array was fabricated and its measured behavior was compared with model predictions. The output vs frequency results (Figure 10)

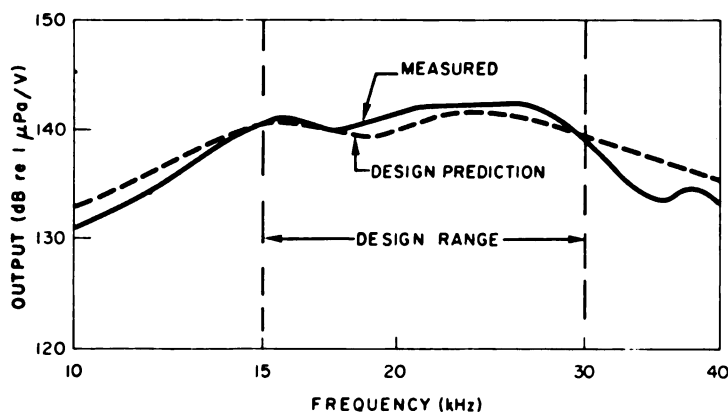


Figure 10. Comparison of the measured transmitting voltage response of the prototype array with that predicted by the model

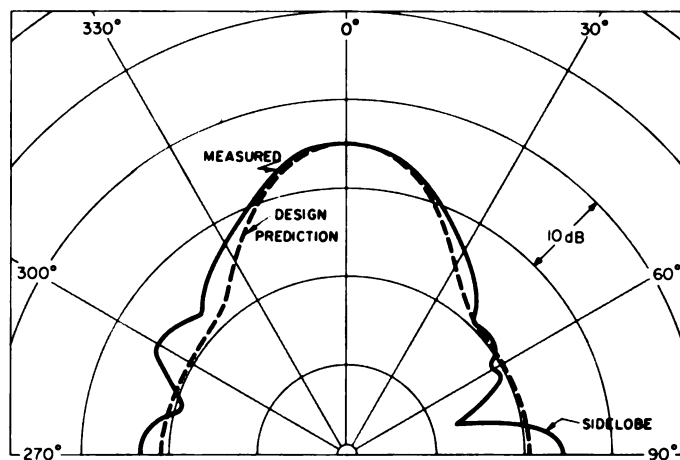


Figure 11. Comparison of the measured vertical (XZ) directivity pattern at 20 kHz with that predicted by the model

showed good agreement in the design range. The agreement between the measured and predicted vertical (XZ plane in Figure 9) directivity patterns (Figure 11) is also good with the exception of some sidelobes (secondary maxima). However, if the requirement for an output that is constant with frequency is relaxed to a constant positive slope with increasing frequency, the sidelobes can be reduced in relative amplitude. The model may be used to determine the array configuration and individual piezoelectric element sizes required to yield the desired slope.

The model is expected to be used in the design of new electroacoustic calibration sources and other transducers with similar requirements.

[Sponsored by NAVSEASYS COM and ONR]

Composite Materials for Underwater Acoustics Applications, by R. C. Pohanka, P. L. Smith, and R. W. Rice, *Material Science and Technology Division*

Piezoelectric ceramic materials are used in sonar devices and hydrophones to interchange sound energy and electrical energy. The most useful of these materials is polycrystalline lead zirconate titanate (PZT) because of its bulk and electroelastic properties. However, PZT is difficult to use in towed or conformal arrays

because of its brittleness and weight. A more flexible material is needed.

NRL scientists are investigating new approaches to develop other piezoelectric and ferroelectric materials to use in improved Navy sonar and acoustic systems. This research seeks to describe the structure vs property relationships of composites and to discover new compounds with improved properties, such as large hydrostatic piezoelectric coefficients, an existing deficiency of PZT.

Structure vs property relationships of composite materials such as ceramic-ceramic and ceramic-organic are being investigated to gain an understanding of specific transduction mechanisms and other special properties not achievable in a uniform or single-phase material. For example, the development of ceramic-organic composites that have the flexibility of a polymer combined with the tailored piezoelectric and dielectric properties of a ceramic could have a major impact on systems such as thin-line towed or hull-mounted conformal sonar arrays which require flexible piezoelectric components. These flexible composites could also be useful in active piezoelectric devices if the piezoelectric coupling coefficient were large enough.

Since 1946 when piezoelectric ceramics were first discovered, numerous attempts to produce a ceramic-polymer composite with a suitable piezoelectric activity have been made. These early composites were produced by mix-

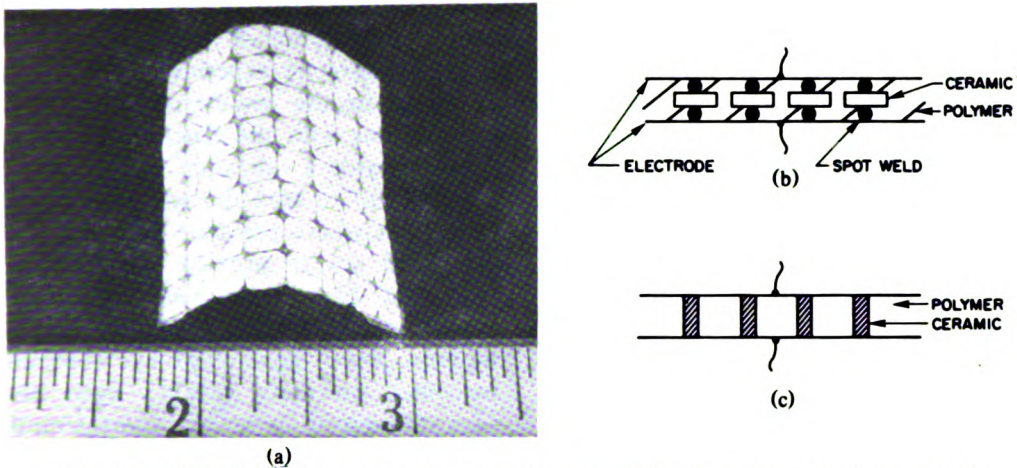


Figure 12. (a) The NRL ceramic-polymer composite designed to be incorporated into a hydrophone. (b), (c) Comparisons of the actual volumes and of the effective dielectric volumes of ceramic and polymer.

ing the ceramic powder in a polymer matrix. However, the piezoelectric activity in these materials was too low to be of practical value. NRL scientists recognized the problem as the lack of dielectric connectivity; *i.e.*, each ceramic grain was shielded from the electrical field by a polymer coating, thus causing a low polarization of the ceramic and low piezoelectric activity. To overcome the problem, they developed a multiphase material (called a macrocomposite) in which small fully polarized ceramic discs are embedded in a flexible polymer sheet (Figure 12). This material is then covered with a thin metal sheet, also flexible but stiff enough to concentrate the acoustic stresses onto the ceramic discs. This concentration of the stress permits the development of maximum charge equal to the charge that would be produced if the sheet were composed solely of the ceramic. The dielectric constant of the composite structure can be varied independently of the charge by appropriate selection of (a) the size and spacing of the discs and (b) the portion of the ceramic surface upon which the electrodes have been painted. Since the voltage output depends on the ratio of the developed charge to the dielectric constant of the composite, useful piezoelectric properties can be tailored to meet various hydrophone requirements. Sensitivities of hydrophones composed of four different materials, including the NRL macrocomposite, are compared in Figure 13.

The experimental values found for the piezoelectric and dielectric properties of the

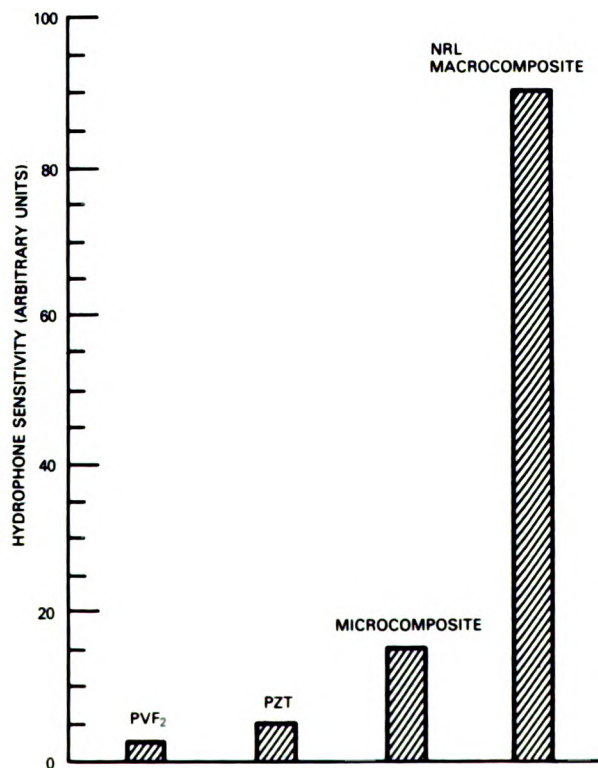


Figure 13. Relative sensitivities of hydrophones composed of four different materials: polyvinylidene fluoride (PVF₂), lead zirconate titanate (PZT), a microcomposite (PZT powder in polymer), and a macrocomposite (ceramic wafers in polymer). Note the greatly improved sensitivity of the NRL-developed macrocomposite.

composite were consistent with values derived from a simple theoretical model developed as part of the NRL research.

NRL researchers have demonstrated that use of ceramic-polymer composites with controlled structures offers a feasible approach to the production of flexible piezoelectric materials. Other composites, such as ceramic-ceramic materials, are also being investigated to provide improved piezoelectric materials for a variety of applications.

[Sponsored by ONR and NAVSEASYS-COM]

Sound Scattering by Rough Surfaces, by S. K. Numrich, *Acoustics Division*

The Navy uses sound extensively for communication, exploration, and information acquisition in the underwater environment. In propagating through the water, sound interacts with a variety of boundaries: the water surface, the ocean bottom, and the under surface of ice in the polar regions. When the boundary is smooth, the sound is reflected in a given direction with easily calculable losses. However, most of the boundaries in the ocean are not smooth. Irregularities that form the surface of a rough boundary scatter the sound in a variety of directions. A thorough knowledge of the mechanisms involved in rough surface scattering and the influence of that scattering on sound propagation is essential to the effective use of sound in the ocean.

Recently completed work at NRL has significantly extended experimental observations of rough surface scattering. The project grew out of the attempt by NRL's scientists to understand more fully the effect of scattering in the arctic environment. It was carried out in cooperation with investigators at the Laboratory's microacoustic modeling facility.

The roughness of a surface is described by the Rayleigh roughness parameter which is proportional to the ratio of the root mean square (rms) height of the surface to the wavelength of the sound. At low frequencies (long wavelengths), well-known mathematical methods such as the Kirchhoff approximation can be used to calculate the scattering losses. As the acoustic frequency increases, the wavelength of the sound becomes small enough to be affected by the small details of the surface; in effect, the surface appears rougher. In this region of increasing roughness, the commonly used

mathematical approximations do not give an accurate description of the observed losses.

A laboratory experiment was designed (a) to begin in the low-frequency region where comparisons with the Kirchhoff approximation would provide a validation of the measurement scheme, (b) to span the region of intermediate roughness where previous data were questionable, and (c) to provide scattering measurements at high roughness where data were inadequate. Statistically random height distributions were generated by computer and machined on metal blocks. Each block was then immersed in water, short sound pulses were directed at it normal to the rough surface (Figure 14), and the sound scattered back toward the source was measured. The scattering loss was expressed as the reflection coefficient, which is the ratio of the scattered to the incident sound. A smooth, perfectly reflecting surface will have a reflection coefficient of 1.0 (0.0 dB).

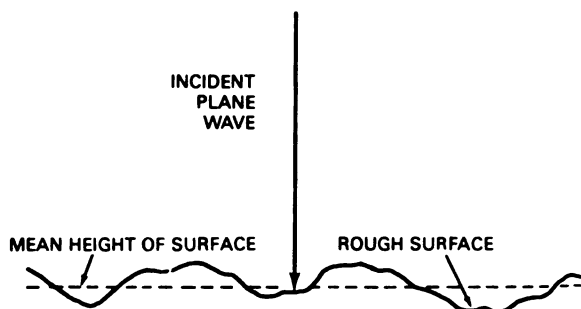


Figure 14. Orientation of the source and surface for all the experiments. The incident sound was normal to the nominal mean height of the surface.

Reflection coefficients obtained from one of the rough surfaces are shown in Figure 15. The range of the Rayleigh roughness parameter was achieved by using short acoustic pulses containing a broad spectrum of wavelengths. Two different sources, low frequency (●) and high frequency (x), were needed to span the desired range of the roughness parameter. As the Rayleigh roughness parameter increases from 0 (smooth, perfectly reflecting surface), more of the sound is scattered into other directions rather than being directed back at the source. This dispersion of the sound field results in a decrease in the reflection coefficient.

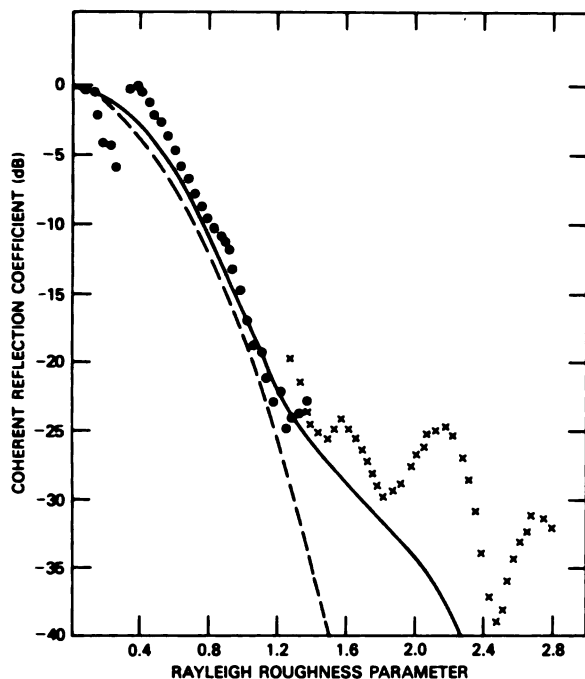


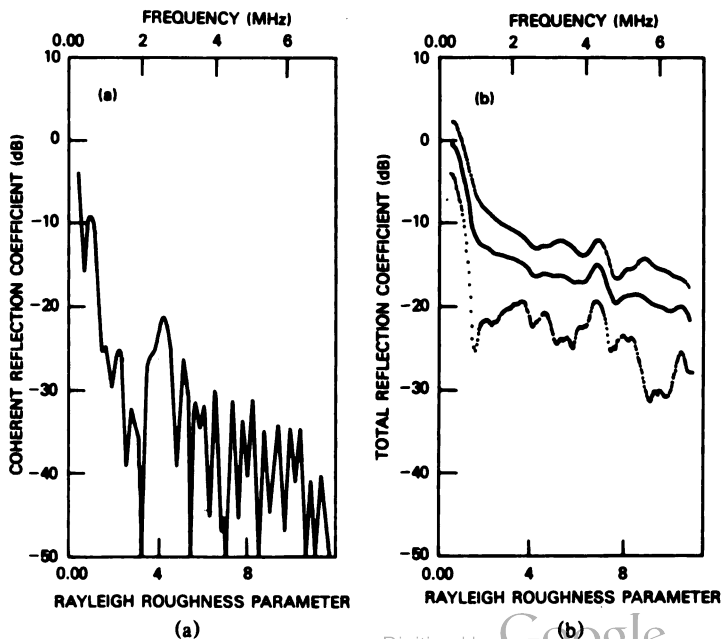
Figure 15. Measured coherent reflection coefficients for a brass surface with rms height of 0.037 cm with a low-frequency (●) and higher frequency (x) source. The Kirchhoff approximation (dashed curve) and a theoretical model developed at NRL (solid curve) are also shown.

Shown with the measured data in Figure 15 are two theoretical calculations; the Kirchhoff approximation (dashed curve), and a less restrictive mathematical model (solid curve) developed at NRL. Both are in good

agreement with the data for small values of roughness. In the region of intermediate roughness (1.5 to 3.0 in the roughness parameter), the measured reflection coefficients begin to deviate significantly from the theoretical predictions. Here, where the wavelength becomes smaller than the distance between maxima and minima of the surface height, sound waves scattered back toward the source from different surface features interfere destructively. This interference or phase cancellation appears in the coherent reflection coefficient as a sudden drop in magnitude. The effect becomes more pronounced as the wavelength decreases (increasing the roughness parameter), allowing smaller surface features to cause phase cancellation. In Figure 16(a), the coherent reflection coefficients shown in Figure 15 are extended into the region of large roughness by using smaller wavelengths. The prevalence of phase cancellation in this illustration was common in scattering measurements from all four surfaces used in the NRL experiment.

In computing the coherent reflection coefficient, only scattered sound that maintains a constant phase relationship to the incident sound is included. By use of different techniques, all of the sound scattered back at the source can be averaged without regard to phase. The resulting total reflection coefficient is shown in Figure 16(b) bounded above and below by limits of one standard deviation.

Figure 16. Reflection coefficients, obtained by transient pulse analysis, as a function of the Rayleigh roughness parameter for a brass surface with rms height of 0.037 cm. The coherent term is shown in (a). The total reflection coefficient (b) is shown bounded by limits of one standard deviation.



These losses point to the redirection of the sound by the surface features.

Transient (short) pulse analysis techniques developed at NRL have made possible the simultaneous extraction of both coherent and incoherent terms from a single set of measurements. Prior to this work, only coherent measurements appeared in acoustics literature and those were confined to roughness parameters of less than 3.0. NRL's new large body of coherent measurements will be used in comparisons with theoretical models. The coherent term is sensitive to individual surface features as a result of retaining phase information. The feasibility of distinguishing different types of surfaces by phase discrimination will be investigated. The total reflection coefficients will be examined for immediate application to a number of Navy problems, particularly those concerned with sound propagation in the arctic environment.

[Sponsored by NOSC and ONR]

Acoustical Behavior of Coated Steel Plates, by A. J. Rudgers, *Underwater Sound Reference Detachment*

Elastomeric coatings are applied to submerged structures to control the sound radiated by these structures as well as to modify their acoustic reflection characteristics. To use such coatings effectively, it is important to determine how their physical properties (such as, density, composition, thickness, and elastic moduli, which are time-dependent quantities) affect the acoustical behavior of the coated structure. NRL scientists are studying methods for evaluating the properties of coating materials and, in the course of this research, have investigated the acoustical behavior of coated, air-backed, submerged plates. A theoretical model of such coated plates has been developed by extending thick-plate theory. This model has made it possible to relate the acoustical behavior of a coated plate to the physical properties of the coating and to the elastic properties of the metal plate itself in a simple fashion.

This analysis produced several significant results. It established an explicit relationship between the acoustic reflection characteristics of coated plates and the behavior of such plates

when they vibrate and radiate sound. The analysis showed that there is a unique function that describes how the sound field, either radiated or reflected by a coated plate, depends upon the properties of the plate, the coating, and the bonding adhesive between them. The analysis also demonstrated that it is not correct to consider a coated plate as equivalent to some homogeneous plate defined by a set of "average" or "effective" material properties. It has been a fairly common practice in the past to introduce such "effective" properties.

The equations describing the acoustical behavior of coated plates were also evaluated by a computer. A submerged steel plate, coated with a homogeneous rubber layer on one side and air-backed on the other side, was studied because of its practical significance. The initial study examined the acoustic field radiated or reflected by steel plates with either of two different elastomer coatings: a soft nitrile rubber with small elastic loss moduli, and a stiffer neoprene with high elastic loss moduli. The objective was to determine how the sound field reflected or radiated by a steel plate is affected by the elastic properties of the coating elastomer.

This initial investigation, however, led to a surprising general conclusion. It was found that neither elastomeric coating, despite their different elastic properties, had a significant effect on the acoustical behavior of the steel plate, even with thick coatings, over the entire frequency range examined. This concept is illustrated in Figure 17, which shows the sound pressure radiated in various directions by an infinitely extended plate that is driven by a concentrated sinusoidally varying force (See Figure 18). The coating is the high-loss neoprene rubber coating at 10°C; and the radiated frequencies are 5 kHz (Figure 17(a)), which is above the coincidence frequency of the plate, and 2 kHz (Figure 17(b)), which is below it. [A coincidence frequency is characteristic of any fluid-loaded elastic plate. At and above the coincidence frequency, elastic structural waves traveling in the plate can couple effectively to an acoustic field in the fluid.] Even with a thick coating, the reduction in the radiated field is no more than 2.2 dB at 5 kHz (Figure 17(a)) and 1.3 dB at 2 kHz (Figure 17(b)). It was also

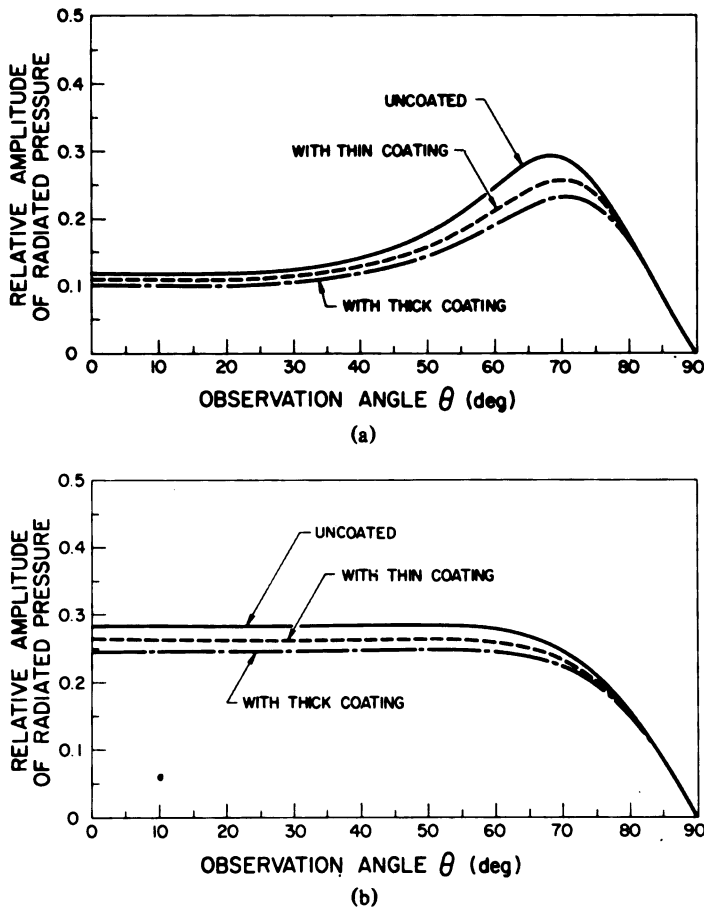


Figure 17. Radiation of sound at 10°C by an air-backed, fluid-loaded, point-excited steel plate coated with neoprene rubber. Plots show the amplitude of radiated pressure as a function of the angle of observation θ with exciting frequency of (a) 5 kHz and (b) 2 kHz.

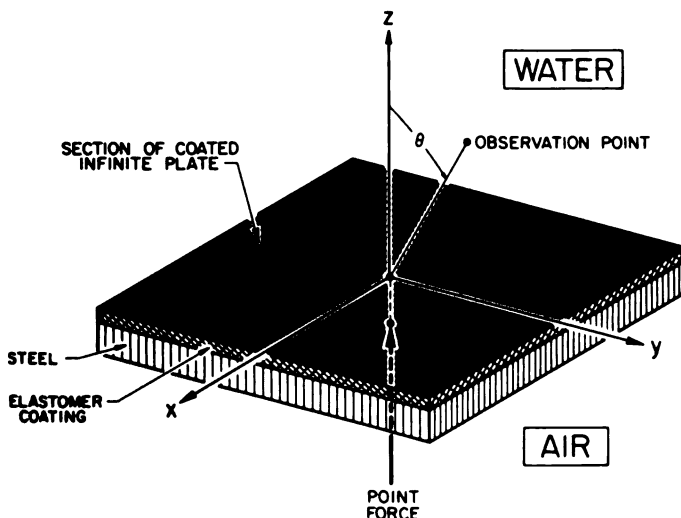


Figure 18. An infinitely extended, air-backed, elastomer-coated steel plate, radiating sound into water. The plate is excited by a concentrated force, varying sinusoidally with time, that is applied to its bottom surface. The observation angle θ is measured with respect to the point of application of the exciting force.

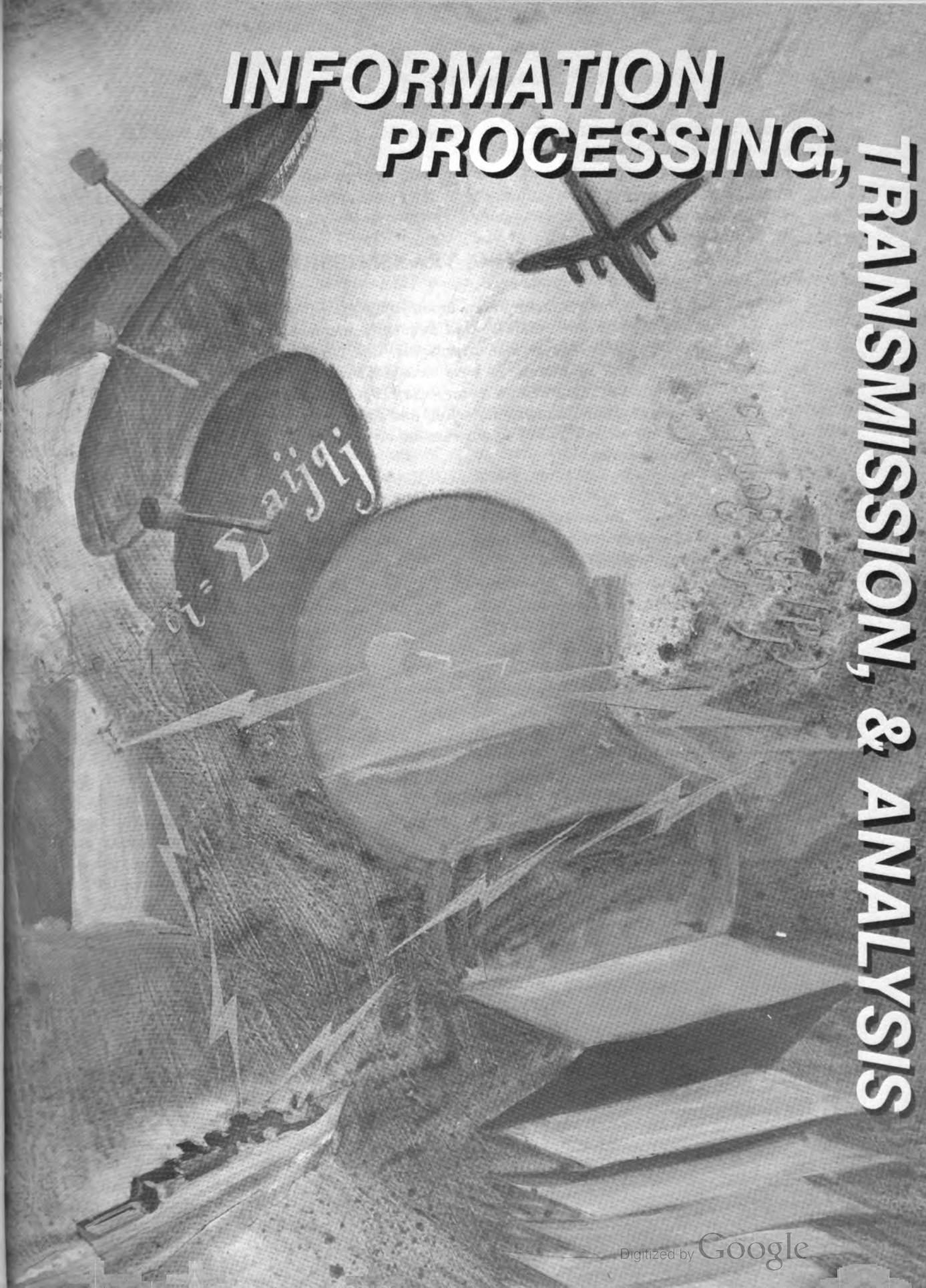
found that the coating was no more effective in reducing the amplitude of reflected sound than it was in reducing sound radiation by the plate.

The ineffectiveness of an elastomeric coating in suppressing radiation from an air-backed steel plate can be explained by the NRL theory. The equations describing the coated plate incorporate the steel and elastomer constants as linear combinations. The elastomer constants, however, are one to several orders of magnitude smaller than the corresponding constants of steel. For example, Young's modulus of a typical steel is $2.2 \times 10^{11} \text{N/m}^2$, but the complex Young's modulus of the neoprene is $[1.2 + j(0.6)] \times 10^9 \text{N/m}^2$ at 10°C and 5 kHz. Any linear combination of the elastic moduli of

steel and elastomer is, therefore, numerically approximately equal to the elastic modulus of steel by itself. Thus an elastomer-coated, air-backed, steel plate may be expected to behave acoustically very much like an uncoated steel plate.

This research will be extended to other types of elastomer-coated structures in the search for improved means of evaluating the acoustical performance of elastomeric materials. Better measurement techniques and greater physical understanding will contribute to more effective use of elastomeric coatings for control of sound reflection and radiation by submerged structures in practical situations.

[Sponsored by ONR]



INFORMATION PROCESSING, TRANSMISSION, & ANALYSIS

INFORMATION PROCESSING, TRANSMISSION, AND ANALYSIS

A modern Navy is faced with a broad range of missions and threats. For the United States, these are worldwide and frequently interdependent, so that its forces must be prepared to take prompt, appropriate, and effective action across a broad spectrum of possible situations. To meet these responsibilities, the Navy must be able to utilize its limited resources with a sure, knowledgeable, and coordinated hand — it must be able to obtain, understand, select, and communicate the necessary information. NRL has many research efforts that are contributing to the realization of these important requirements.

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Robust HF Communications, by J. M. Morris,
Communications Sciences Division

The Navy, through several development programs, is seeking better performance in HF communication systems which are characterized by electromagnetic interference (EMI) from many sources. In scenarios of Navy HF communication, the potential for severe EMI is great from both intentional and unintentional sources. Several investigations are under way at NRL and elsewhere to solve EMI problems for post-1985 HF communication systems by developing new signal waveform designs and reception methods. Robust receivers, an approach being investigated at NRL, is based on the *minimax* and *maximin* approaches of game theory. (In either case the communicator is trying to minimize the maximum or worst-case loss. In a sense, the maximin strategy applies to unintentional or brute-force interference, and the minimax strategy applies to intentional and intelligent jamming.)

Robust reception is a practical alternative for situations, such as HF communications, in which the specific interference model that will be valid at a given time is not known *a priori* and for which an adaptive receiver would be too costly. In general the robust receiver is not adaptive; it has a fixed structure based on the designer's knowledge of the types of interference sources expected or believed possible. Robust receivers attempt to capitalize on available knowledge of the interference sources while protecting against the types of variations that are most likely to arise. A performance level is guaranteed for a large class of interference models rather than for one specific model such as white Gaussian noise.

In contrast, an optimal receiver requires a specific interference model for complete design. The price paid is that the optimal receiver can perform poorly when the actual interference differs, even slightly, from the interference model. At the other extreme, nonparametric reception requires essentially *no* knowledge of the interference expected. (The term "nonparametric" is used because the set of possible interference models is so large that it cannot be indexed by a finite number of parameters.) The price paid is that the performance of nonparametric receivers is usually poor in light of the knowledge that is available.

Part of the NRL effort has been devoted to studying published results in robust detection theory and assessing their applicability to HF communication problems. As a result of the study's recommendations, an effort is under way to modify and extend those of the results that apply to HF communication problems.

Another aspect of the effort has been to develop a new, direct solution to the robust reception problem as it applies to HF communications. This direct approach is based on generalized Lagrange multiplier theory on the function space $L_1[\Omega]$, which is a mathematical method for solving optimization problems. With use of a standard form for the probability of error (that of Bayes risk for equally likely binary signaling), both minimax and maximin detection problems were formulated. These were solved explicitly for single-sample measurements. Both minimax and maximin detection models as well as the corresponding worst-case interference types were found. The characteristics of worst-case interference depend on the signal waveforms and the receiver's measurement range. Surprisingly, if the interference amplitude has a uniform probability density rather than the worst-case maximin density, the effect is only slightly less. Since the minimax and maximin performance values are not equal, a nonrandomized detector scheme to cause the two values to be equal does not exist. However, a randomized detector scheme to equate these values was found.

These results provide an insight into the multisample robust reception problem whose solution is required for determining robust HF waveforms. It appears conceptually equivalent, and possibly less complicated, to treat dependent random interference by modeling the probability densities as multivariate functions defined on N -dimensional Euclidean spaces and to use existing techniques to obtain a solution. Moreover, additional constraints on the interference model can be handled conveniently in the problem formulation by adding constraints on the multivariate functions. With this approach in mind, some proposed HF-noise models are being validated and will be incorporated into the research effort.

In a related issue, functional analysis was again used to solve the problem of worst-case interfering waveforms for multiple-waveform

signaling and receivers using predecision correlation. The worst-case additive interfering waveform was obtained in terms of the sum of the signal waveforms and the average-power and peak-amplitude upperbounds on its Fourier transform. Worst-case performance can be expressed explicitly in terms of this waveform. This result will be useful in the design and evaluation of signaling waveforms for *existing* receivers. It will also be useful for the evaluation of receivers under unfavorable conditions, as is the purpose in some tactical electronic-warfare-environment simulation programs.

NRL is exploring the feasibility of HF signal waveform designs and reception methods that are robust, and of algorithms for evaluating the performance (including worst case) and the worst-case interference for arbitrary designs. As more theoretical results are obtained from these investigations, a software testbed will incorporate the results. This will allow the design and evaluation of signal waveforms and reception methods under various unfavorable conditions.

[Sponsored by ONR]

Multiplatform Sensor Integration, by G. V. Trunk, *Radar Division*

To allocate resources, design battle strategies, and achieve effective fire control, naval forces require clear and unambiguous knowledge of the tactical environment, encompassing all friendly, hostile, and neutral platform position movements within the range of their weapons and defenses.

NRL has contributed to this requirement in the past by developing new techniques for integrating the several radars found on a single ship. This development provided many of the basic concepts and techniques currently being employed. The measured positions of targets detected by two or more radars are merged into a single time-sequenced data stream, and the target tracks are updated sequentially with new detections. This integrated radar tracking concept was realized through simple timing and bookkeeping procedures, as well as simple, but nearly optimum, filter realizations for accommodating the characteristics of different radars.

More recent work has considered a multi-ship environment with the initial effort being

directed toward integrating the radars only. The basic concept, as presently envisioned, is shown in Figure 1. It is analogous to the concept used in integrating the radars aboard a single ship, but there are two distinct differences. A small subset of the "best" detections, with their associated positional data, is merged into a time-sequenced data stream and the target tracks are sequentially updated. Although all of the detections from all of the radars on all of the ships could be used in the track updating process, the load placed on the intership communication system would be enormous. For this reason, only the "best" detections on each target are transmitted over the communication link. ("Best" detections are those having the largest signal-to-noise ratio, affording optimum triangulation with other platforms, *etc.*) This reduces the required channel capacity with little degradation in track quality. The mechanism for achieving this concept is simple and allows the system to be flexible in the amount of data required for each track. Specifically, a sequence of time slots is provided, into which each platform inserts its "best" detections, provided these are better than those already available. A system manager controls this process, and may ask for data of a specific quality. The other distinct difference between the single- and multiple-radar integration systems is the way in which the track files are organized. For the multiple-platforms system, the track file is divided into four major mutually exclusive categories: (a) tracks having primary local interest and being controlled and updated by one's own ship; (b) tracks of participating platforms supplied by the navigation system (used for sensor bias removal); (c) tracks being controlled and updated by other platforms; and (d) tentative tracks. This method of operation distributes the work load among the participating platforms, and yields a system which is relatively unaffected by the loss of any one of its members. The development of new data processing techniques and algorithms has been necessary to realize these exciting new concepts and procedures. During 1978, a simulation of the system was developed in order to test algorithms for selecting the "best" detections and to estimate the bandwidth requirements for the data link.

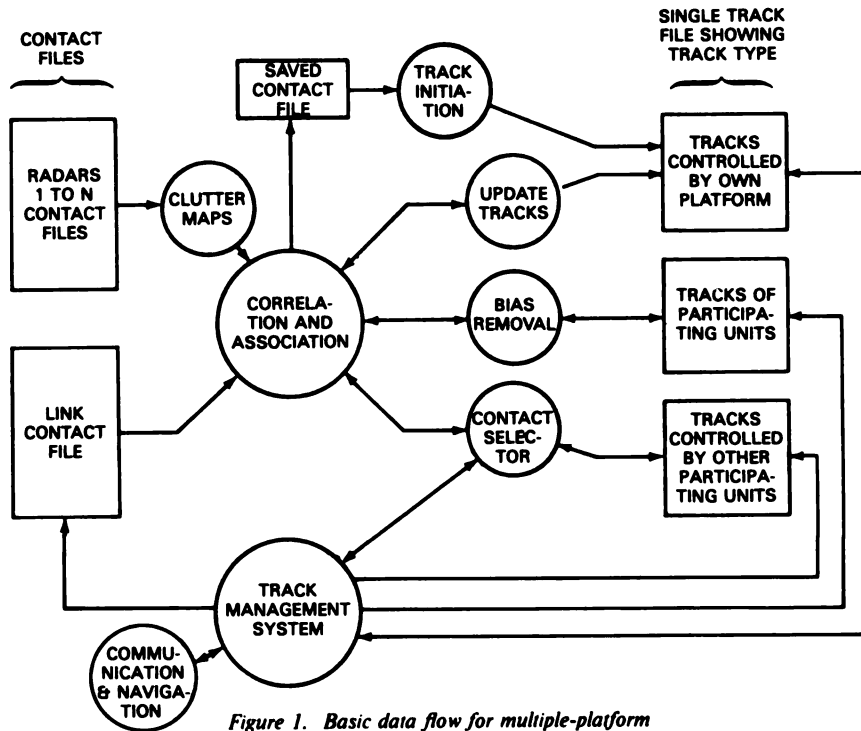


Figure 1. Basic data flow for multiple-platform radar integration

A similar problem deals with IFF (Identification, Friend or Foe). Radar and IFF can provide useful information to one another. The important task here is the integration of target identification information obtained from more than one type of system. One approach to this using IFF as the base is called "IFFN Fusion," where IFFN is the acronym for identification, friend, foe, or neutral, and the word "fusion" means that the information available from different sources, not necessarily collocated, is to be "fused" for a common purpose. Four sensor types have been selected for use in building a candidate fusion system for detailed study and/or testing. This candidate fusion system will, of course, be integrated with the best possible radar techniques, as well as other sensors that provide clues to identification.

[Sponsored by NAVSEASYS COM and USAF]

Information Theory and Applied Probability, by R. W. Johnson and J. E. Shore, *Communications Sciences Division*

The need to choose a probability distribution from an infinite class of distributions satis-

fying a set of constraints is a problem encountered in signal processing, reliability estimation, queuing theory, statistical mechanics, and other fields. The probability distribution to be selected might be that for a system such as a signal corrupted by noise, a weapon system with parts subject to failure, a queue of requests for service in a computer, or an assemblage of molecules. There are various formalisms for making the choice, and the value of one approach or another has been a matter of continuing controversy. One such approach is the use of *principle of maximum entropy*, or its generalization the *principle of minimum cross entropy*. In the past year, work at NRL has produced results that should lead to wider acceptance and use of this approach.

Assume that it is necessary to choose, under a set of constraints, a probability distribution q for the states of some system (where q_j is the probability of the j th state). Let the constraints have the form of prescribed values, or prescribed bounds on the values, of the expectations $e_i = \sum_{ij} a_{ij}q_j$, of given quantities a_{ij} . The principle of maximum entropy is to choose, among all the probability distributions q

that satisfy the constraints, the one with the greatest *entropy*. Entropy is defined as $-\sum_j q_j \log q_j$.

The principle of minimum cross entropy is used when a prior probability distribution p exists: a family of state probabilities p_j that would be valid in the absence of the constraints. The principle is to choose that q , subject to the constraints, that minimizes the *cross entropy*, $\sum_j q_j \log (q_j/p_j)$. The principle of minimum cross entropy reduces to that of maximum entropy when all the probabilities p_j are equal.

Controversy over these principles has existed between those who see them as a uniquely correct procedure for taking constraint information into account and those who see them as arbitrary or ad hoc. The former point out that entropy and cross entropy are quantitative measures of information; they cite theorems showing that entropy is uniquely characterized by axioms that state desirable properties for an information measure, and they argue that the maximum-entropy distribution should be regarded as the one that agrees with what is known but presumes the least quantity of extraneous information, or expresses "maximum uncertainty" regarding what is unknown. There are similar axiomatic characterizations of cross entropy and similar arguments for the principle of minimum cross entropy. For the skeptics, such arguments at best lend intuitive plausibility to the principles but do not provide a compelling answer to the question: Why minimize cross entropy rather than some other function?

The approach taken at NRL was to give a direct formal characterization to what is required of a procedure for taking new information into account, rather than a characterization of what is required of an information measure. A set of axioms was constructed that expresses the need for such a procedure to yield consistent results. An informal phrasing of these axioms that an acceptable procedure must satisfy is that the results of using the procedure to take new information into account should be unique and be independent of:

- the choice of coordinate system;
- whether independent information about independent systems is accounted for separately

in terms of different probability densities or together in terms of a joint density; and

- whether information about an independent subset of the system states is accounted for in terms of a separate conditional density or in terms of the full system density.

It was then proved, given a prior distribution and new information in the form of constraints on expectation values, that only one distribution satisfying these constraints can be chosen by a procedure satisfying the axioms, and that this unique posterior distribution can be obtained by minimizing cross entropy.

Subsequent NRL work has shown that this result suggests a new technique for solving the classical problem of estimating power spectra (power distribution of signals as a function of frequency) from samples of the autocorrelation function (a function of delay measuring similarity between a signal and the same signal delayed in time). This technique differs from previous ones in a number of ways, but most important is that it incorporates prior estimates of the power spectrum. Under certain circumstances the new technique reduces to the technique known as *maximum-entropy spectral analysis*. The recent results on cross-entropy minimization also add new significance to results obtained in earlier NRL studies in queuing theory.

[Sponsored by ONR]

Forward Scatter Multipath Measurements, by A. Elia, R. Gurney, and D. Northam, *Tactical Electronic Warfare Division*

When a radio-frequency (RF) signal is transmitted above a reflecting surface, the energy incident on a receiving antenna is the vector sum of the direct and surface-reflected components of the transmitted signal (Figure 2). This distortion of the direct signal by reflected signals is commonly referred to as multipath. The strength of the reflected signal is a function of many parameters, among which are the conductivity and roughness of the reflecting surface, the grazing angle at the surface, the polarization of the transmitted signal, and the radiation patterns of the transmitting and receiving antennas.

Knowledge of the effects of multipath over the sea is mandatory for the analysis,

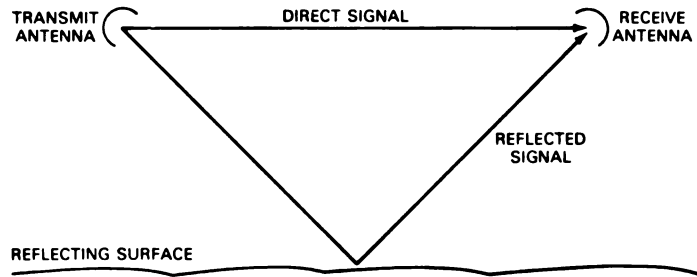


Figure 2. Basic multipath situation. The signal at the receive antenna is the vectorial summation of both the direct and reflected signals.

modeling, and design of electronic counter-measures (ECM) systems. It is, therefore, necessary to understand and characterize forward scatter over natural sea surfaces.

An over-water experiment was designed to measure the amplitude and phase fluctuations of an RF signal at various frequencies, grazing angles, and antenna polarizations. A CW signal was transmitted, and the receiver sampled this signal at two rates, 1 kHz and 625 kHz. The slower sampling rate produced data corresponding to pulse-to-pulse sampling in a typical radar, while the faster rate was used to obtain data within a pulse repetition interval (PRI), during which time the radar return signal is received. Wave height, wind speed and direction, temperature, pressure, and humidity data were collected simultaneously with the RF data.

The transmit system (Figure 3) consisted of a synthesized signal source, traveling wave tube amplifier (TWT), polarization switching circuit, and parabolic antenna. The synthesized signal generator has a long-term stability of 5 parts in 10^{10} /day; this very high stability was required to ensure that there would be no degradation of the measurements due to frequency drift in the generating source. The polarization switching circuit allows the selection of either horizontal, vertical, or one sense of circular polarization for transmission. The parabolic reflector antennas have a nominal 6° beamwidth radiation pattern with sidelobes more than 20 dB below the maximum of the main beam.

The receive system (Figure 4) consists of 20 dB standard gain antennas, RF mixer/preamps, IF processor, analog/digital processor,

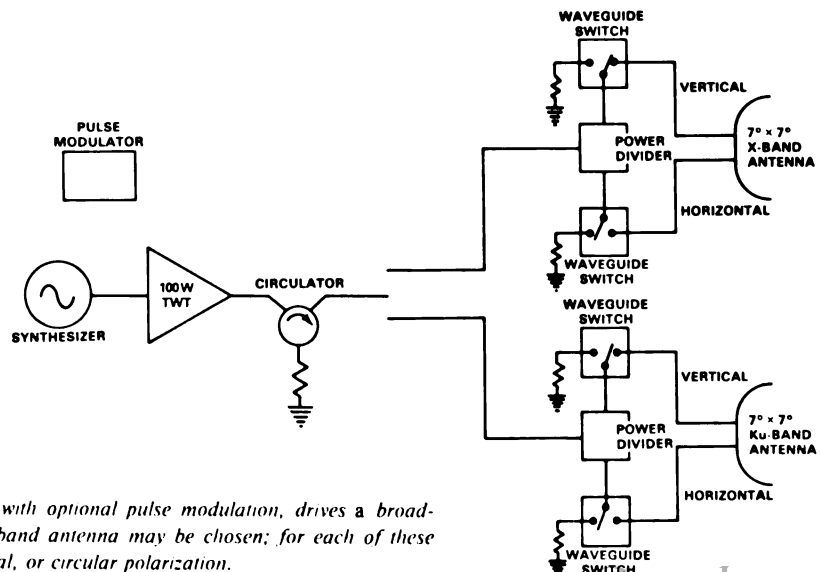


Figure 3. Transmitter. The synthesizer, with optional pulse modulation, drives a broadband 100-W TWT. Either an x- or ku-band antenna may be chosen; for each of these waveguide switches select horizontal, vertical, or circular polarization.

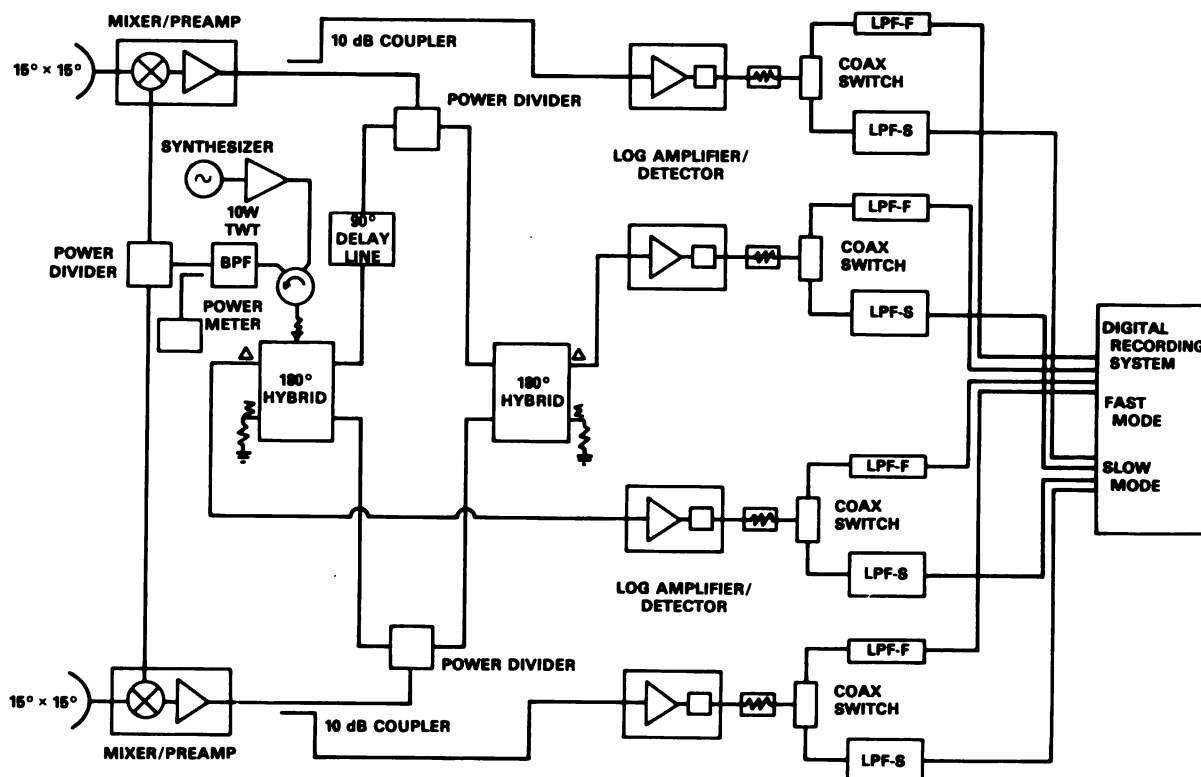


Figure 4. Multipath measurement system. The two RF signals are mixed down to 60 MHz and processed by the hybrids and log amplifiers to yield the amplitude and difference signals. After passing through filters, the four voltages are digitized and recorded on magnetic tapes.

and digital tape recorder. The RF signals received at the antennas are mixed to produce two 60 MHz IF signals. These are operated on by the IF processor to produce four video outputs that are the amplitudes and vectoral difference of the two signals. The two difference channels vary from one another in that the inputs to one RF hybrid in Figure 4 are in phase and the inputs to the other are 90° out of phase. This implementation is important because it allows the phase difference between the two channels to be calculated from either the sine or cosine function. Analytical and empirical sensitivity analyses have indicated that the sine function was more accurate in the 45° to 225° region, while the cosine function was more accurate over the remaining phase angles.

Each of the four outputs of the IF processor is fed through low-pass filters to the analog/digital processor where they are amplified, sampled, and converted to a digital signal before being recorded on 9-track magnetic tape.

The data on these tapes have been preprocessed in preparation for detailed statistical analysis. The preprocessing has removed the linear and nonlinear effects on the data due to such equipment contributions as component attenuation and phase shift, and performed the phase angle calculations using the optimum difference channel. The preprocessed data (now stored on disc memory) are an accurate representation of the actual physical process which took place during the field tests.

The data will be used to develop a model of radio frequency multipath over the sea. This phenomenon, most critical at low grazing angles, must be clearly understood when analyzing both the tracking of targets by a radar seeker and the operation of EW systems.

The construction of the model requires knowledge of first- and second-order statistics (such as probability density type and parameters, covariance type and parameters) and their dependence on environmental, radar, and geometric parameters. These will be obtained from the data by using various statistical tech-

niques incorporated in a general purpose statistical analysis package. This powerful package was developed under the multipath program since no equivalent package was available with the required capabilities.

The authors wish to acknowledge the help of Gregory Hrin who devised and performed much of the extensive component calibration, installed equipment, and assisted during the field testing.

[Sponsored by NAVELECSYSCOM]

Computer/Processors for EW, by L. W. Lemley, *Tactical Electronic Warfare Division*

The performance of sensors, and especially those used in electronic warfare (EW), is rapidly overtaking the capability of processing the information they provide. The "choke point" in the flow of information from sensor-to-user is the sensor preprocessor (Figure 5). In a typical threat signal environment, this may be expected to perform 100 operations on a 56-bit data word at the rate of one-million data words per second. Even the most advanced computers with unlimited volume and weight cannot meet this requirement. At present, the EW problem is managed by statistical sampling with analog devices. However, these devices are highly customized and cannot be easily standardized to provide the simplicity required for broad Navy application.

Studies performed at NRL indicate that computer performance is most economical for the Navy when it is based on a broadly used commercial computer architecture that is tolerant of technological improvements. In this manner, improved performance capabilities can be implemented as they evolve, without requiring new architectures and new software. Architectures with such technological tolerance have already been demonstrated, and their performance has remained clearly competitive with specialized hardware while avoiding a \$25 million investment in a new software inventory.

The performance of a computer/processor is measured by its "throughput," which is the total useful information processed in a given period of time, and is primarily dependent on memory technology. Optimum throughput results when the arithmetic processor and memory are equal in speed so that neither need wait on the other for execution. This is true of

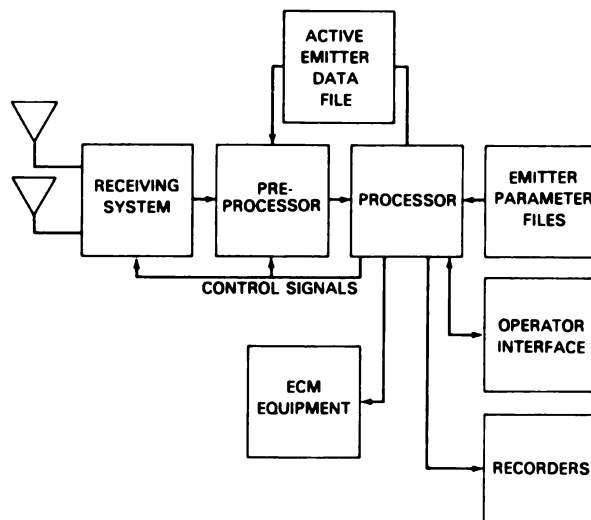


Figure 5. Typical ESM system

almost all architectural schemes. In the special interest area of EW, the most significant performance improvement (after improvements in basic memory speed) results from optimized (EW) microinstruction timing. Software (tools) has the least effect on performance.

Technologically, throughput performance is dependent on a property of the memory called its "speed-power product," which is the product of propagation delay and the power dissipated in the memory, and should be small for high performance. Microcircuit technology usually follows closely the basic technologies of high-speed memories. High speed requires short path propagation times, which are achieved by high component densities within the memory. This, in turn, leads to power dissipation problems which define a technological barrier at a speed-power product of one 1 pJ at room temperature (Figure 6). The introduction of higher density circuits through very large scale integration (VLSI) is not sufficient to improve performance. These higher density circuits must display improved speed-power products, which is generally achieved by lowering the operating voltages. As lower operating voltages are introduced, however, technology must cope with the increasing error and electromagnetic interference (EMI) that become important at the smaller signal-to-noise (S/N) ratios associated with low-voltage VLSI circuits.

The major characteristics of all computer processors are dominated by the speed-power

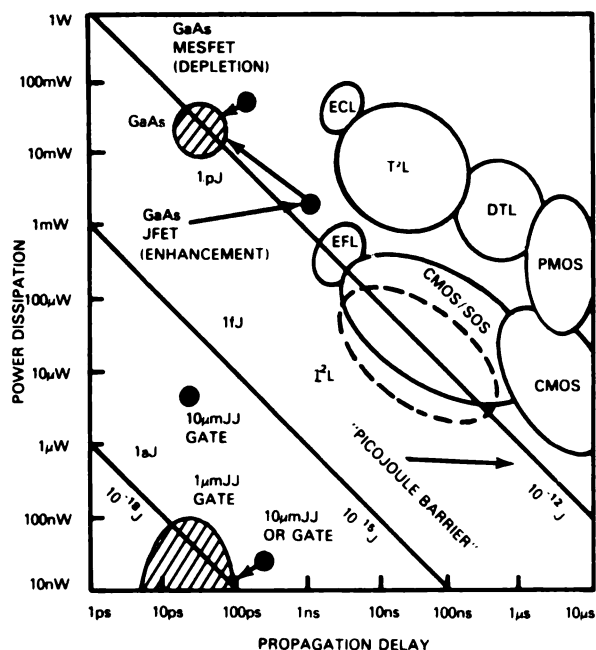


Figure 6. The "picojoule barrier" in power dissipation vs propagation delay for various logic technologies. The bubbles indicate demonstrated performance of the indicated technologies. The highest speed-power products are anticipated for the Josephson Junction (JJ) devices.

product. Throughput is affected as noted above, but so are weight, volume, power, and cost. High throughput can be achieved simply by building larger machines up to some finite limit, but the throughput per weight, or power, or volume are dominated by technology. The speed-power product is the dominant single characteristic correlating to weight, volume, power, and cost. If research and development continue in the pattern of the past 20 years, computer/processors can anticipate order-of-magnitude reductions in cost (based on throughput) every 10 years, and in weight and volume every 5 years. Technological advances should improve throughput by an order-of-magnitude every 7 years, although this cannot be expected to appear at once in commercial or military products.

[Sponsored by NAVAIRSYSCOM]

Software Process for Emitter Ambiguity Resolution (SPEAR), by S. S. Leroy, *Tactical Electronic Warfare Division*

The determination of electronic signal identification in the area of electronic warfare

(EW) operations has become an increasingly complex problem. This is due not only to the fact that there are a great many signals in EW environments, but also to the overlap or similarity of their electrical characteristics or parameters. To improve our ability to understand and analyze this problem, NRL has developed SPEAR, which is a set of computer programs consisting of three basic phases: (a) retrieval of signal-type data from some existing data base; (b) determination of overlapping parameters in a sequential manner between each emitter type; and (c) analysis of ambiguities with variable user-defined constraints.

The SPEAR software has been designed in a file-oriented and computer program (task) modular manner. That is, the basic philosophy of the approach is that each task uses a file or set of files as an input, and produces as an output a file or set of files to be used by a follow-on task. In this manner, the required programming is kept at a simple level, the user or the system has more direct control of each step in the process, and task size limitations are not encountered. In addition, the output files can readily be examined for correctness and integrity after each step.

In the retrieval phase, the desired data are extracted from some available data base and stored into separate computer files. These separate files are more amenable to modifications in data, sorting, and other operations, and they also provide the remainder of the SPEAR software with a data interface which is logically and physically independent from the source data base, and more efficient for SPEAR purposes. The only requirement is that software be written to perform this data extraction for each distinct data base structure.

The parameter overlap determination phase is the fundamental and uniquely powerful feature of the SPEAR system. Its strength lies in its techniques for determining whether, and how much, overlap or ambiguity exists between any two signal types with respect to some chosen data base parameter.

Structurally, parameters are currently considered to consist of 1, 2, or 3 computer words. One-word parameters are examined according to a user-chosen trichotomy ($<$, $=$, $>$) relationship for defining the meaning of overlap. For example, a signal type is either friendly or

hostile. Only one data word is needed to describe the desired parameter. Overlap between two signal types is declared if their values are equal to each other. In this case, the probability of overlap on the friendly/hostile word is either 0 or 1. Two-word parameters, such as a range of operational values, can be examined by means of interval intersection (binary mode) or by assigning probability density functions (density function mode). For example, signal type frequency requires two data words which specify lower and upper frequency limits. The same is true for other parameters such as pulse repetition interval and scan rate. If we let (A_1, B_1) represent the limits of operation of a parameter for signal type number 1 and let (A_2, B_2) be the limits for signal type number 2, then overlap or ambiguity can be determined either by comparing the limits directly to each other or by applying a probability density function to these limits. Figure 7(a) displays how the overlap is determined in the traditional direct manner. In this case, the operational values lying between A_2 and B_1 represent the overlap. Figure 7(b) displays a uniform density function applied to the same set of values. In this case, not only the existence of overlap is determined, but also its amount, as depicted by the shaded region in the figure. Figure 7(c) displays the application of a normal density to each of the parameter limits, with the shaded region again indicating the amount or probability of overlap. In applying the density function mode, a Romberg variable step size integration is performed when necessary between the densities of each signal type to determine the probability of overlap. Three-word parameters are a combination of one- and two-word parameters, where the two-word techniques are applied if, and only if, the one-word analysis fails to resolve the ambiguity (*i.e.*, to distinguish one signal type from another in the parameter overlap determination phase). For example, the jitter parameter consists of three words: the jitter type, and lower and upper limits. If two signal types being compared have different jitter-type codes, then they can be distinguished on the basis of jitter and therefore are said to be resolved. If not, the analysis must continue by analyzing the jitter limits in the manner previously discussed for two-word parameters.

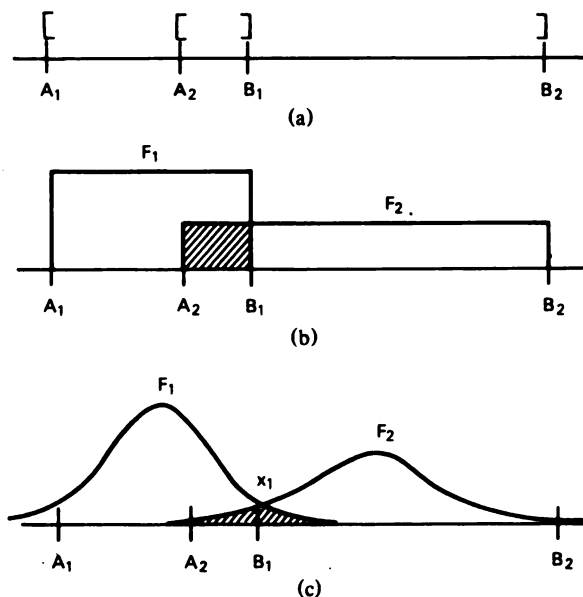


Figure 7. Determination of overlap of two signal types with limits A_1, B_1 , and A_2, B_2 by (a) binary mode, (b) uniform density function mode, and (c) normal density function mode

The uniform and normal density functions are currently in use, but the software can easily incorporate any other desired functions. In this phase, the computed overlap probabilities can be compared with a minimum threshold value, and those signals with insignificant overlap probabilities (*i.e.*, below threshold) can be physically removed from further consideration.

The analysis phase consists of five distinct tasks that provide tabular and graphical summaries of resolution effectiveness; that is, the degree of success achieved in distinguishing a set of signal types from each other. Individual sequences of signal-type parameters can be examined in detail and in the ensemble, as in Figure 8, and sets of sequences also can be compared by means of payoff matrices constructed on the basis of assigned benefit-to-cost ratios on each parameter in a sequence. As a result, sequence rankings can easily be performed by computing sequence payoff means. Figure 8 provides a complete sample analysis of the effectiveness of six different parameter sequences. The sequences are labeled S1 to S6 (see inset in Figure 8) and the parameters are frequency (F), pulse repetition interval (PRI), pulse width (PW), pulse position modulation (PPM), jitter (JIT), stagger (ST), and scan rate

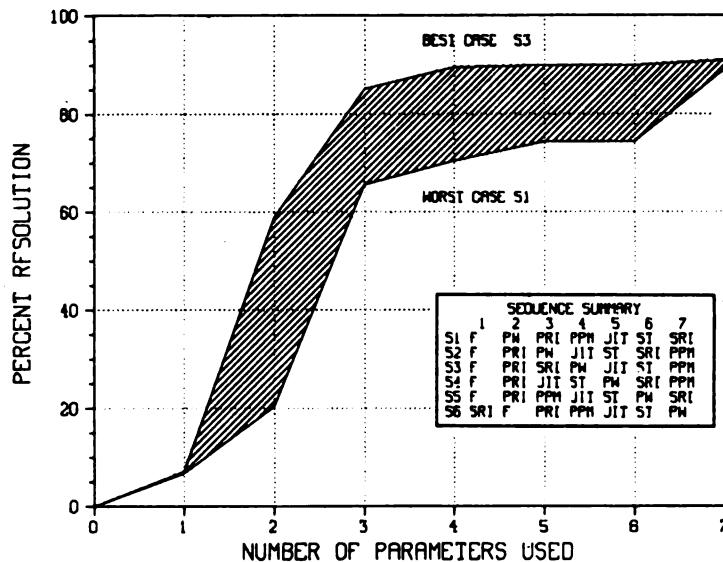


Figure 8. Data base resolution envelope for six different parameter sequences (S_1 to S_6)

interval (SRI). The best sequence for distinguishing all the signal types in the chosen data base is S3, since approximately 85% of the signal types are resolved by using three parameters, namely F, PRI, and SRI in that order. The worst case is sequence S1, which requires all seven parameters to achieve 85% effectiveness. The other four sequences generate results which fall in between these two.

Thus far, SPEAR has been used successfully in support of Navy efforts in determining the significance of particular parameters within signal identification algorithms. As a by-product, it is expected that the SPEAR process can also be utilized effectively to provide refinements in the parameter measurement process of existing collection systems as well as in the creation of optimal on-line signal identification libraries.

[Sponsored by NAVELECSYSCOM]

Narrowband Digital Voice Terminal, by W. M. Jewett, *Communications Sciences Division*

The Department of Defense has the stated goal to encrypt all military voice-communication circuits. The encryption requires that the voice signal be digitized, and communication-bandwidth limitations dictate that the digital data rate be reduced from that of conventional digitization. (A digital data

rate of 2400 bits per second (b/s) is a DoD standard for narrowband (3-kHz) communication circuits, whereas conventional digitization (at a rate high enough to sample every half cycle at all frequencies in the voice signal) typically results in a data rate of about 50,000 b/s.) Recent advances have been made in the analysis and synthesis of voice using linear-predictive-coding (LPC) techniques, which base an estimate of the current intensity level of the speech waveform on previous levels. With a 2400-b/s data rate, the quality of LPC speech is now superior to that obtained with conventional vocoders, which are not predictive and perform the analysis/synthesis in the frequency domain. As a result, DoD has specified the use of LPC techniques in all near-term narrowband digital voice terminals.

An advanced narrowband digital voice terminal (ANDVT) is being developed by the Navy to satisfy all DoD tactical requirements. Its principal features are a 2400-b/s LPC, an HF modulator/demodulator pair (modem) with error-correction coding, and a provision for data encryption. NRL is acting as technical advisor to NAVELEX in the development of engineering models of the ANDVT. In support of this program, NRL has been investigating improvements in LPC algorithms, the sensitivity of LPC analyzers to background noise, the application of error-correction coding to LPC data, and

alternative system architectures for an integrated terminal. The results of these investigations have been synthesized into a terminal specification issued in 1978. This terminal specification represents the first attempt by DoD to develop a narrowband digital voice terminal as a single unit, with parameter values specified to maximize overall system performance. Particular emphasis has been placed on reducing the effects of transmission errors on the synthesized voice and on increasing the probability of successfully establishing a secure circuit when operating in nets, where multiple users share a common frequency assignment.

Most tactical requirements for encrypted narrowband voice are being satisfied by HF radio links. Operational modes include long-range point-to-point communications as well as the shorter-range nets. To transmit encrypted LPC data with conventional single-sideband HF radio equipment that is designed to transmit audio frequencies, it is necessary to use a modem pair to transform the digital data signal to an audio-frequency signal and back again to digital data. The format of the audio-frequency signal must be such that performance is reliable in a time-varying, multipath channel with non-Gaussian additive noise. The specifications for the ANDVT ensure that its design will exploit advanced technology for improved performance and efficient implementation. The following are some of the advanced techniques being incorporated into the HF modem:

- A multiple-tone signal format and an adaptive-threshold detector maximize performance on a channel with nonuniform fading over the frequency band. Error-correction coding is employed, and data are permuted to minimize the effects of narrowband interference and frequency-selective fading.

- A doppler estimation algorithm provides for accurate frequency tuning. Decision-directed doppler tracking provides for improved performance in a fading channel and makes maximum use of the available bandwidth by eliminating the need to transmit special doppler control signals.

Although HF digital voice is expected to be the primary mode of operation for the ANDVT, there are provisions for a number of auxiliary modes which will increase its utility. These auxiliary modes provide an economical

means of integrating the terminal into existing communication systems and will facilitate its use in future systems.

[Sponsored by NAVELECSYSCOM]

Improving Navy Software, by K. Heninger, A. Parker, and D. Parnas, *Communications Sciences Division*

Control logic in military electronic systems is often implemented with computer software rather than hardware, because it is then easier to change when requirements change. However, military software is typically poorly documented, poorly organized, and hard to understand. Software maintenance (both the correction of errors discovered during use and the introduction of improvements requested by the Fleet) has become a major life-cycle expense for Navy systems.

To improve the reliability and maintainability of military software, NRL is developing a disciplined approach to software construction. The approach integrates several techniques such as structured programming, abstract interfaces, and mathematical specifications. Major factors in the approach are the division of software into components that can be developed, understood, and changed independently; rigorous specification of component interfaces; and control of interactions among components.

Use of advanced software engineering techniques should lead to substantial savings in the billions of dollars spent annually by the Navy on software. However, the approach is unfamiliar and difficult, and there are no fully worked-out examples that can be used as models. Designers fear that programs developed by the new approach will run too slowly and require too much computer memory. Therefore, the first step toward gaining general acceptance is to demonstrate the effectiveness of the approach for a substantial example.

NRL has embarked on a joint project with the Naval Weapons Center (NWC) to use the new approach to redesign an existing military software system, the operational flight program for the A-7E aircraft. The new program will undergo the same acceptance tests as the old one, and the two programs will be compared for resource use and ease of change. The goals of the project are to demonstrate the usefulness of the approach for systems with stringent

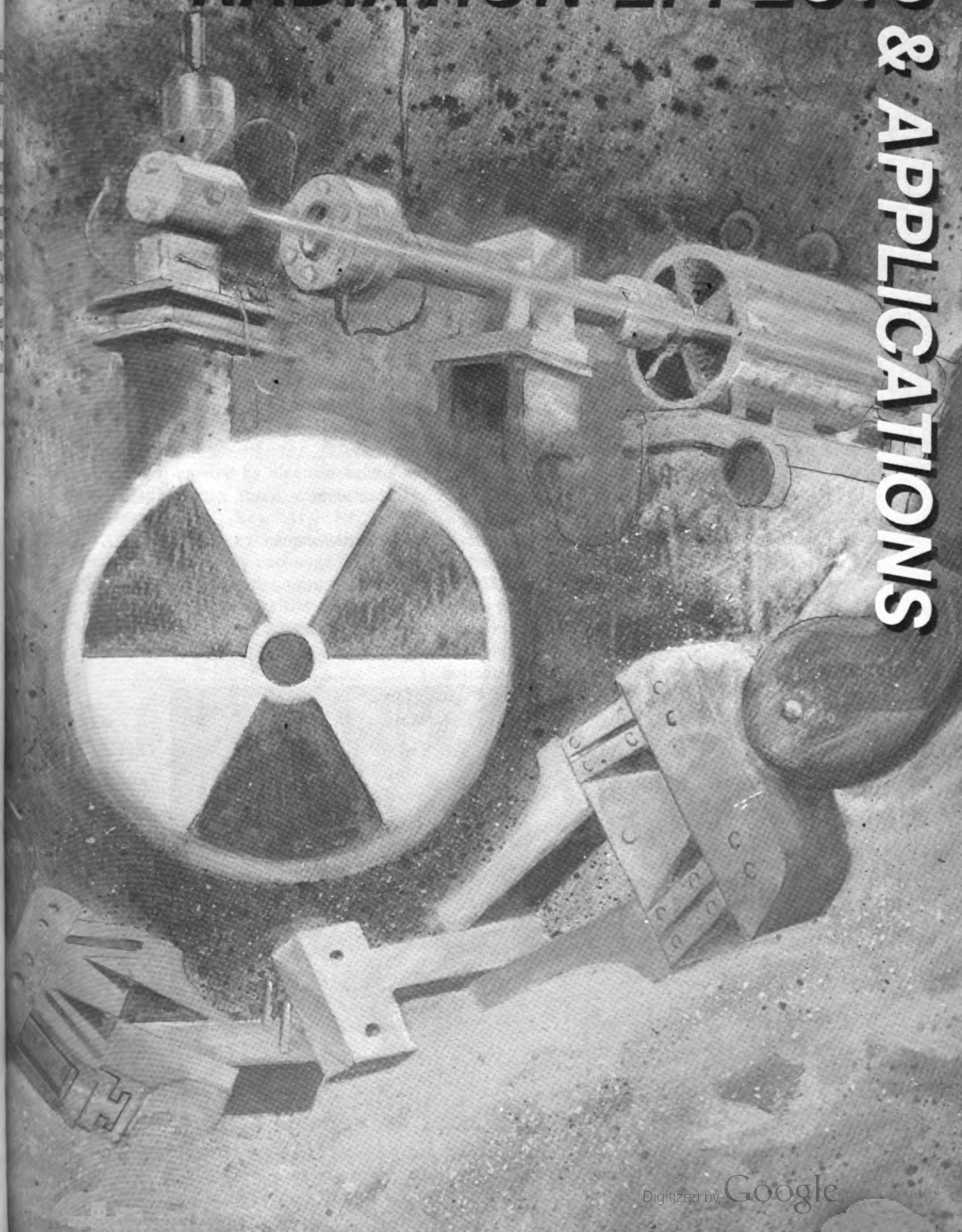
resource limitations and to provide a model for designers of complex military software.

A statement of A-7 software requirements is the first product of the project. Many of the problems with military software stem from incomplete, imprecise, or ambiguous specifications. To produce a complete description of the A-7 software requirements, NRL developed a set of documentation techniques designed to make requirement specifications precise, concise, and easy to check for consistency and completeness. The resulting software-requirements document is easy to change in response to changing requirements, and the organization allows specific questions to be answered rapidly. The document lists constraints on the system developer and describes the externally observ-

able behavior of the software without mentioning any internal details. The techniques separate details of hardware characteristics (which will change only if the hardware is changed) from software behavior (which will change if the software is required to perform new functions with the same hardware). Extensive use is made of formal notation and tables to allow for computer-aided cross-referencing and consistency-checking. Maintenance personnel at NWC are using the software-requirements document to train new A-7 programmers and to derive additional test cases. The document is also being used by designers of other systems as a model of good requirements documentation.

[Sponsored by NRL and NAVMAT]

RADIATION EFFECTS & APPLICATIONS



RADIATION EFFECTS AND APPLICATIONS

The nuclear revolution of the past three and a half decades has wrought many profound changes in our world. Increasing applications in power generation, propulsion, analysis, and weaponry have stimulated expanded efforts to understand the properties and effects of the radiations involved and to mitigate or utilize them. During 1978, NRL continued its tradition of productive contributions in this field.

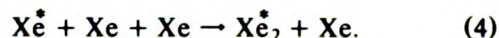
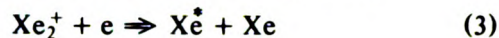
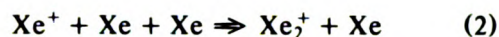
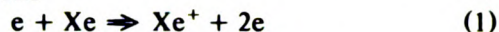
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Proton-Beam Excitation of High-Pressure Gas Lasers, by A. W. Ali, J. Golden, W. Jones, and C. A. Kapetanakis, *Plasma Physics Division* and J. G. Eden, *Optical Sciences Division*

In 1978 the first application of high-energy proton beams as a pump source for lasers from a high-pressure (greater than atmospheric) gaseous mixture was demonstrated at NRL. This development places proton beams among several other well-established pump sources, e.g., electron beams, electron-beam sustained discharges, and ionizing radiations. The proton beams, however, are expected to produce higher laser power densities from high-pressure gaseous mixtures than electron beams now used. Therefore, they present an attractive pump source for high-power and perhaps more efficient lasers.

Lasers from high-pressure gaseous mixtures have been excited by electron beams and can be classified into three categories. The excimer lasers (e.g., Xe_2 , Ar_2 , Kr_2 , XeF^* , KrF^* ...), the charge exchange lasers (e.g., He_2^+-N_2), and the energy-exchange lasers (e.g., Ar^+-N_2). The common denominator in these lasers is that they depend at the outset on the ionization produced by the passage of the electron beam. For example, the kinetics of the

xenon excimer laser can be summarized by the equations



The upper laser level, Xe_2^* , is produced in the last step. However, as seen in the equations, the higher the ion density (Xe^+ in step 1), the higher the inversion density and the higher the laser power density that can be obtained. Of course, the degree of ionization has a limit beyond which the free electrons could adversely affect the laser output. In adapting the equations to proton beams, high-energy protons replace high-energy electrons in the first equation of the above Xe_2 laser kinetics.

Since atoms have greater stopping power for protons than electrons of the same energy, the protons deposit more energy per unit path as they traverse a given gas, and therefore produce more ion pairs. Thus, protons produce a higher inversion density and a higher laser power density.

The proton beam device utilized for laser applications is shown in Figure 1. Parameters

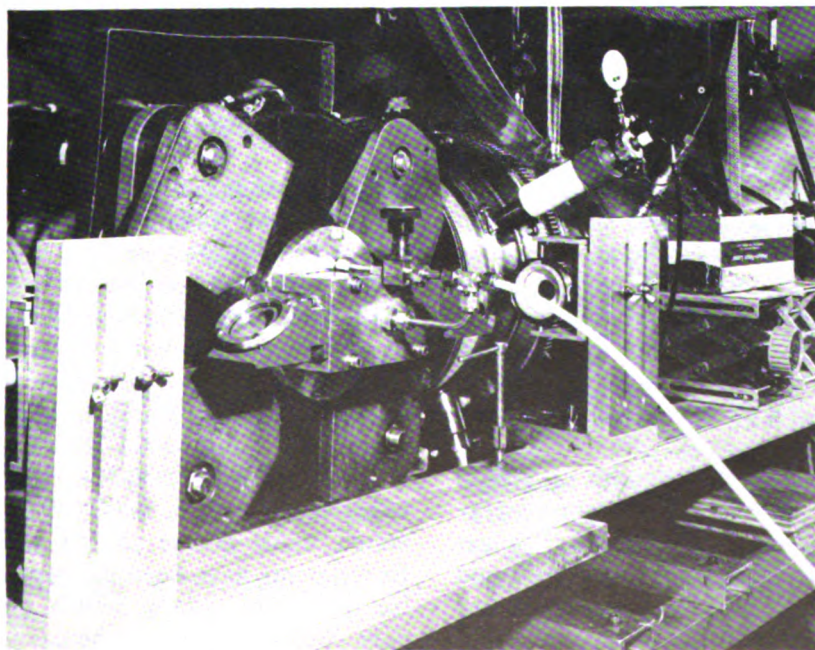


Figure 1. Proton beam generator system. The gas cell and laser cavity are in the box just left of center. The optical axis parallels the base.

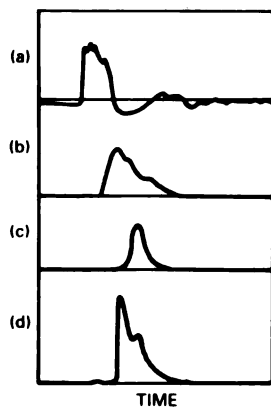


Figure 2. Waveforms generated by an Ar-N₂ laser excited by a proton beam showing (a) Anode voltage (approximately 520 kV peak), (b) Fluorescence of 95% Ar, 5% N₂ mixture at 1 atm, (c) Laser pulse at 1 atm, and (d) Laser pulse at 1.5 atm. Each time graduation is 50 ns; vertical scale is arbitrary.

of typical beams are proton energies of 0.1 to 1.5 MeV, currents of 1 to 300 kA, and current densities of 0.1 to 70 kA/cm². The first waveforms of proton-pumped lasers from an Ar-N₂ (Ar $\gg$ N₂) mixture at $\lambda = 3577 \text{ \AA}$ are shown in Figure 2. Figure 3 shows the fluorescence and the narrowing of the line of the laser transition. This wavelength corresponds to the (0,1) transition of the second positive band system in nitrogen. It arises as the result of the resonance energy exchange between an excited (metastable) argon atom and a nitrogen molecule. The preliminary laser energy extracted from the laser cavity with a cavity output of 0.1% was 10^{-5} J for a fill pressure of 1.5 atm of Ar with 5% of N₂. The optimum laser output, however, will have to await careful laser cell designs and stronger proton-entry windows that will allow higher pressures ($>1 \text{ atm}$) in the gas cell. Theoretical modeling of the Ar-N₂ laser system shows that higher laser power densities can be obtained using proton beams with current densities lower than electron beams. For example, 600-keV electrons with a current density of 100 A/cm^2 produce a laser power density of 5 kW/cm^2 compared to 80 kW/cm^2 for 250-keV protons of current density 20 A/cm^2 in a 4:1 mixture of Ar:N₂ at 1 atm.

Plans to exploit the potential of proton pumping of lasers include use of higher energy proton beams, better gas cells with stronger windows to accommodate higher pressures, and systematic studies of lasers with high power potentials. Coupled with detailed theoretical modeling of individual lasers, those studies will lead to the development of compact, high-

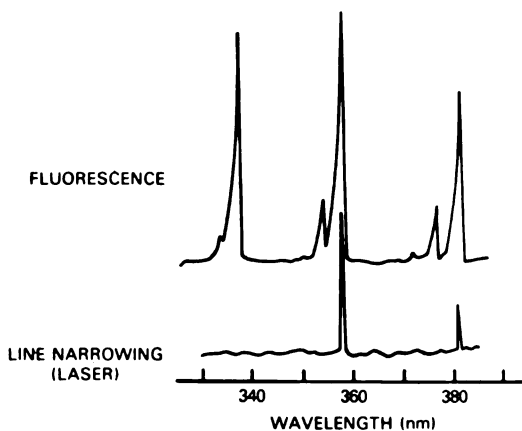


Figure 3. Densitometer traces of fluorescence (top) and laser emission (bottom) spectra

power laser devices applicable in the medical, communications, and fusion energy fields.

[Sponsored by ONR]

Radiation-Induced Noise in CCDs, by W. C. Jenkins, J. M. Killiany, and J. A. Modolo, *Electronics Technology Division*

Charge-coupled device (CCD) imagers have some applications in environments that have high background levels of gamma radiation. The gamma radiation generates a charge in the CCD which is indistinguishable from the charge in the real signal. In addition, the noise on the spurious radiation-induced charge is larger than the shot noise on an optically generated signal charge of the same magnitude. Experiments have been performed to characterize this noise, and a simple model has been developed to relate it to the device thickness.

For a quantum efficiency of unity, one electron-hole pair is generated in silicon by

each optical photon. Therefore, the number of equivalent noise carriers associated with N optically-generated charge carriers collected in a CCD potential well is $\sqrt{N}$, corresponding to the fluctuation component of the optical flux. The number of electron-hole pairs produced by a typical gamma ray photon over a path length L is given by the empirical expression $90L$ when L is expressed in micrometers. In a CCD imaging system, a picture is made up of many picture elements (pixels). Each pixel corresponds to one charge-collecting potential well or photosite. The number of electron-hole pairs, P , created per gamma event in the pixel collection volume is, therefore, a function of the average path length of a gamma-generated electron in the volume. For a pixel having the shape of a flat, shallow rectangular parallelepiped, the average path length is very nearly equal to the thickness D of the pixel. This means that $P \approx 90D$.

The number, N , of electron-hole pairs generated in a pixel volume by E gamma events is therefore

$$N = EP.$$

The shot noise associated with E gamma events is $\sqrt{E}$. Therefore, the number of noise carriers associated with N gamma-generated carriers is $P\sqrt{E}$. The noise associated with the gamma-generated charge carriers is larger than the shot noise on the desired optical signal and can be larger than the optical signal itself. In comparing the noise produced by the same number (N) of electron-hole pairs generated by the two mechanisms, the relative amplitude of the noise on the gamma-generated charge is described by a quantity called the shot noise multiplier, M :

$$M = \frac{\text{Noise associated with } N \text{ gamma generated charge carriers}}{\text{Noise associated with } N \text{ optically generated charge carriers}}$$

Substituting into this expression gives the important result:

$$M = \frac{P\sqrt{E}}{\sqrt{N}} \approx \sqrt{90D}.$$

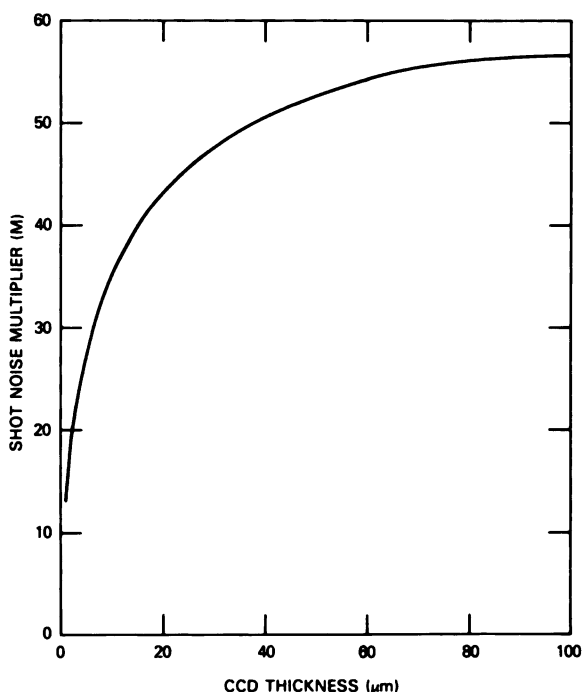


Figure 4. Calculated values of M as a function of CCD pixel collection volume thickness (pixel dimensions $25 \times 125 \mu\text{m}$, minority carrier diffusion length $39 \mu\text{m}$)

Thus the model predicts that the shot noise multiplier is proportional to the square root of device thickness for devices thinner than the surface dimensions of a pixel.

The predicted values of M as a function of device thickness are shown in Figure 4 for a pixel having lateral dimensions of $25 \times 125 \mu\text{m}$ and an assumed minority carrier diffusion length of $39 \mu\text{m}$. The figure shows that little reduction in M can be expected until the thickness of the device is smaller than its lateral dimensions.

Figure 5 shows a block diagram of the experimental setup to test the model. The CCD under test is placed in a test chamber which is lowered into the ^{60}Co gamma radiation source. A DC restoration circuit establishes a reference level for the signal. The signal from a selected pixel of the CCD is sampled and fed to an analyzer for spectral analysis of the noise voltage. The number of equivalent noise electrons is measured by integrating the noise spectrum. This is accomplished by a computer program that digitizes the spectrum analyzer plots and performs the required integration.

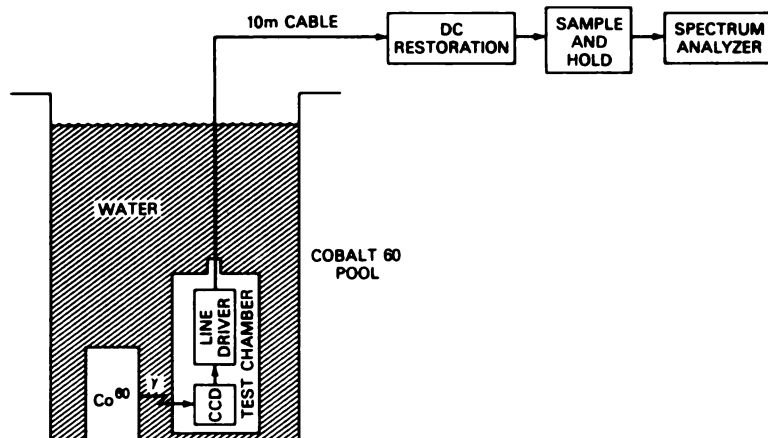


Figure 5. Block diagram of experimental test setup

Gamma noise data were collected on several devices by using the following procedure. The device was first operated to measure the system noise. It was then placed in the gamma source where the noise and amount of generated charge were measured. Then the device was removed from the source, sufficient carriers were injected optically to generate the same charge as the gamma rays had produced, and the noise was again measured. Both the rate and total dose of gamma radiation were sufficiently low to avoid radiation damage effects on the subsequent optical measurements. The ratio of the gamma noise to the optical noise gives the shot noise multiplier. The measurements gave M values ranging from 42 to 46 for typical CCD imagers as compared to the model prediction of 53. This agreement is considered quite encouraging and the experiments are being extended to an NRL charge injection device (CID) with an electrically variable active layer thickness to permit direct observation of the effect of device thickness on M .

[Funded by Navy SSPO]

Radiation Effects in Optical Fibers, by E. J. Friebele, M. E. Gingerich, and L. M. Hayden, *Optical Sciences Division*

Optical data links will be deployed on many military surface, air, and space platforms which might be exposed to nuclear radiation during their lifetimes. The radiation-induced degradation of transmission in the optical fiber waveguide used for the data link is therefore of crucial importance. Scientists at NRL have

been involved in a program to evaluate and characterize the radiation response of optical fibers, to identify sources of the radiation sensitivity, and to develop radiation-resistant glass compositions for the fibers.

One of the most common commercial fibers consists of a germanium-doped silica core with a borosilica cladding. This fiber offers a combination of low intrinsic loss and high bandwidth, and can be made in either single- or multi-mode form. In many instances, the core is also doped with boron and/or phosphorous to alter the thermal properties of the preform rod from which the fiber is drawn. These dopants have been found to substantially alter the radiation response of the fiber as well.

In characterizing the radiation response of an optical fiber, it is generally necessary to determine the change in optical absorption as a function of radiation dose, time after irradiation, and wavelength of the optical signal. Typical radiation-induced attenuation at a wavelength of 820 nm in germanium-doped silica-core fibers vs dose measured *in situ* during ^{60}Co irradiation is shown in Figure 6. The damage in the fibers codoped with phosphorous in the core increases almost linearly with radiation dose, while those containing only germanium or germanium and boron in the core show a saturating behavior due to their recovery. Since these latter fibers experience significant recovery during the time required to achieve a given dose, the induced loss at low dose rates is less than that at high dose rates, accounting for the discontinuity in the lower set

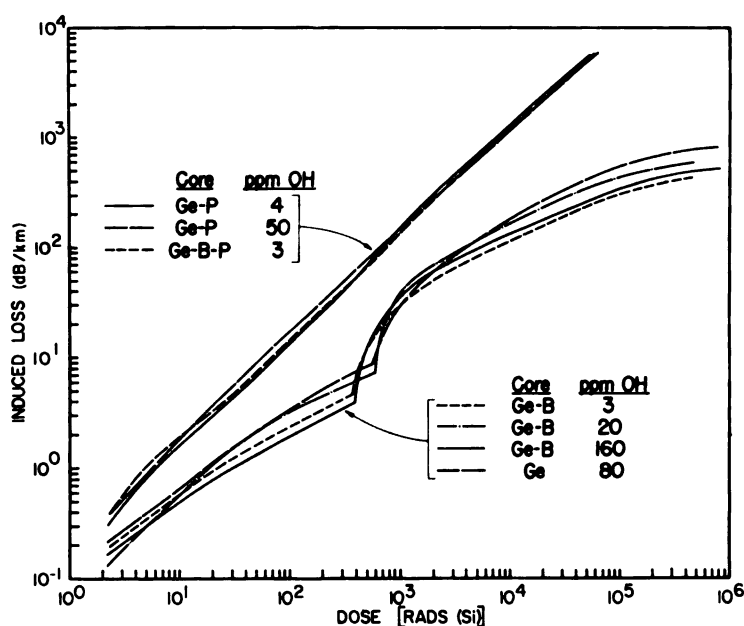


Figure 6. Radiation-induced loss in Ge-doped silica core fibers at 820 nm measured during in situ ^{60}Co irradiation. The discontinuities in the data are due to a change in dose rates from 700 rads/min ($<10^3$ rads) to 18 000 rads/min ($>10^3$ rads)

of curves in Figure 6. Note, also, that the presence of phosphorous greatly increases the radiation response during the irradiation, an effect due in part to the decreased recovery in these fibers. The finding that radiation-induced damage in these fibers is independent of hydroxyl (OH) content is important because it is desirable to lower the OH content to decrease the intrinsic loss of the fibers at 820 nm.

The short time recovery of the optical fibers following high dose rate irradiation is of concern for applications where nuclear bursts may be encountered. The induced loss following a 3 ns pulsed electron-irradiation is shown in Figure 7. The fibers without phosphorous in the core show a very large initial absorption which decays in about 10 s at 25°C. This transient absorption has been associated with electron trapping by the germanium ions in the fiber core. The addition of phosphorous suppresses this intense germanium-related absorption, so that these fibers are preferable for systems which must function immediately after the irradiation pulse. However, the long-term recovery in these fibers is much worse than that in the phosphorous-free fibers since large permanent losses can be induced.

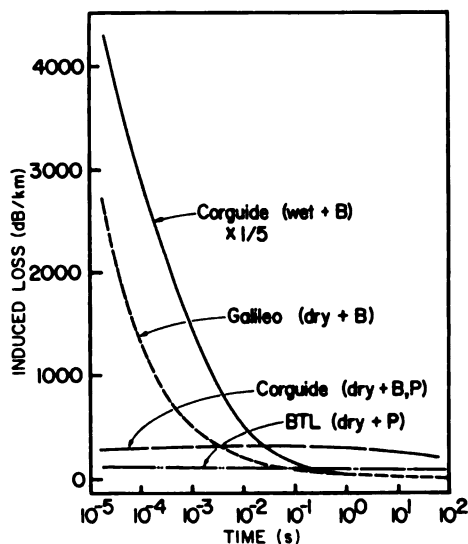


Figure 7. Decay of radiation-induced loss in Ge-doped silica core fibers at 820 nm following a 3 ns, 3700 rad dose of 0.5 MeV pulsed electrons (wet = 40 to 60 ppm OH, dry = 1 to 5 ppm OH)

The spectral dependence of the radiation-induced loss is important not only to understanding the damage mechanisms responsible for the absorption but also for the designer in choosing an optimum operating wavelength for

an optical communications system. The radiation-induced absorption spectra of two representative commercial germanium-doped silica fibers 1 h after ^{60}Co irradiation are shown in Figure 8. The sharp absorption bands in the boron-doped fiber are the overtone and combination bands of the OH in the fiber core. Once again, it is apparent that the addition of phosphorous increases the permanent damage. The increasing absorption toward shorter wavelengths in both fibers is due to the tail of a germanium defect center, and the broad band centered near $1.7\ \mu\text{m}$ has been associated with the presence of boron in the core. It is easily seen that the optimum operating wavelength for these fibers is near $1.05\ \mu\text{m}$ where the damage is several times less than that observed at $820\ \text{nm}$.

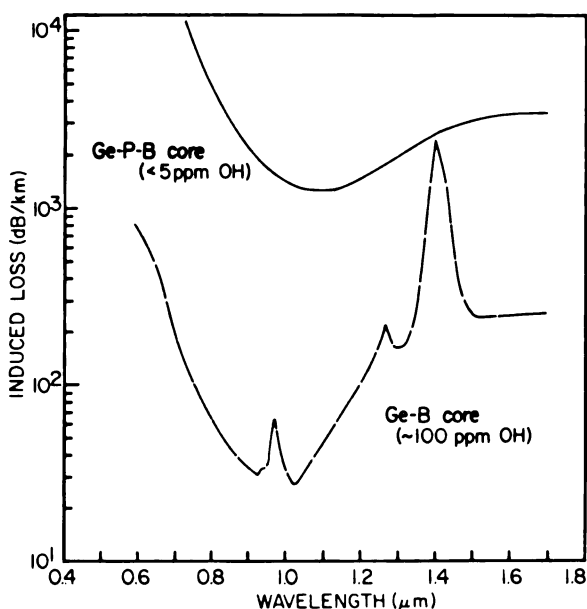


Figure 8. Radiation-induced optical absorption in Corning Ge-doped SiO_2 core fibers following ^{60}Co irradiation (1 h after 10^5 rads)

The results of the NRL studies have provided designers of military optical systems with data necessary to select optimum fibers and operating wavelengths for systems deployed in a radiation environment. These studies have also provided an understanding of some of the mechanisms responsible for radiation damage in optical fiber waveguides and have identified dopants, such as phosphorous, which are

beneficial in certain applications. New fiber compositions continue to emerge as commercial suppliers seek to achieve lower loss, higher bandwidth, and radiation resistance, and NRL is continuing to evaluate their radiation response characteristics. Of particular interest is the behavior of the fibers in the long wavelength region where some of the future optical communications systems will operate.

[Sponsored by ONR and DNA]

Radiation-Induced Defect Structures in a III-V Semiconductor, by T. A. Kennedy and N. D. Wilsey, *Radiation Technology Division*

Radiation-induced point defects in crystalline semiconductors affect their electrical conductivity and the performance of devices made from them. Since the III-V semiconductors, such as GaAs, InP, and GaP, are becoming increasingly important to Navy microwave and optoelectronic applications, it is necessary to learn more about point defects in these materials. A complete understanding of a point defect must include its production rate in a given radiation environment, its microscopic structure, its energy level, and its annealing characteristics. For many defects in Si, many or all of the above properties have been deduced. However, in the III-V semiconductors, little specific knowledge of the existence of lattice vacancies or anion-cation replacement defects (antisites) has been available. This situation has improved in the past year with the identification of two defects in electron-irradiated GaP at NRL.

In a perfect III-V crystal lattice, the electrons are paired off in covalent bonds. Defects do not match the regular lattice atoms and thus often have an unpaired electron. Electron paramagnetic resonance (EPR) is the resonant absorption between the spin states of the unpaired electron, and it can be used to identify and study the defect. Through the resonance line positions, line multiplicity (splittings), if any, and line width, the EPR reveals the local symmetry of the defect and local magnetic fields produced by nearby nuclei that have magnetic moments. EPR has been successfully used to identify point defects in Si and II-VI compounds. In III-V compounds, the lines are broad and weak because of the strong local

or hyperfine fields produced by the III-V nuclei; thus EPR is more difficult.

GaP, with relatively small nuclear spins, represents a favorable case for EPR studies. After being irradiated at room temperature to produce point defects, p-type material exhibits an anisotropic multi-line EPR spectrum at 77 K (see Figure 9). The multiplicity of lines arises from local hyperfine fields. The number of lines observed and their intensity ratios indicate that the unpaired spin has four equivalent phosphorus (^{31}P) neighbors. The anisotropy further indicates that the electron wave function has a large amount of p-character, suggesting that the sp^3 covalent bonds of the GaP lattice are broken at the defect. These results demonstrate that the spectrum arises from an electron at a vacant Ga lattice site (see Figure 10).

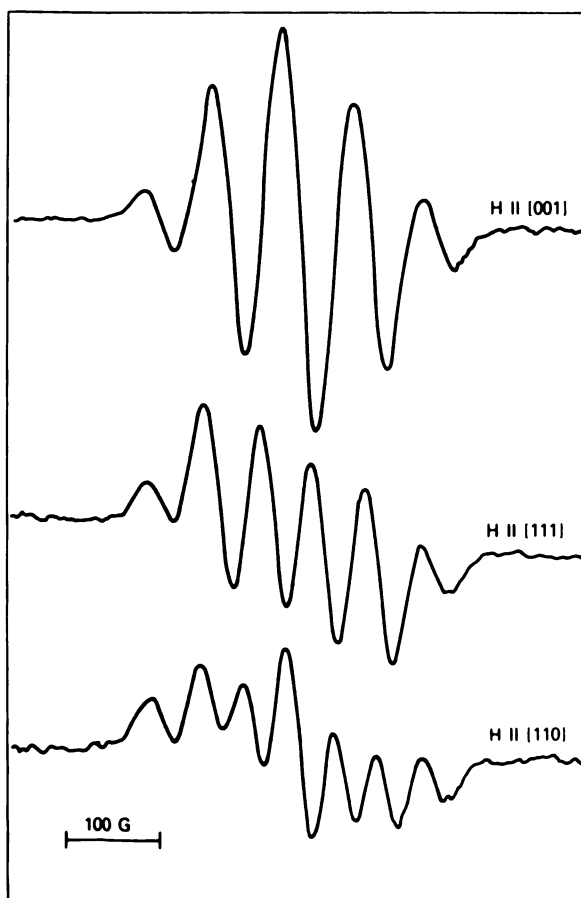


Figure 9. EPR absorption derivative spectra at 9.06 GHz for electron-irradiated p-type GaP. Data for three magnetic field directions in the (110) plane are shown.

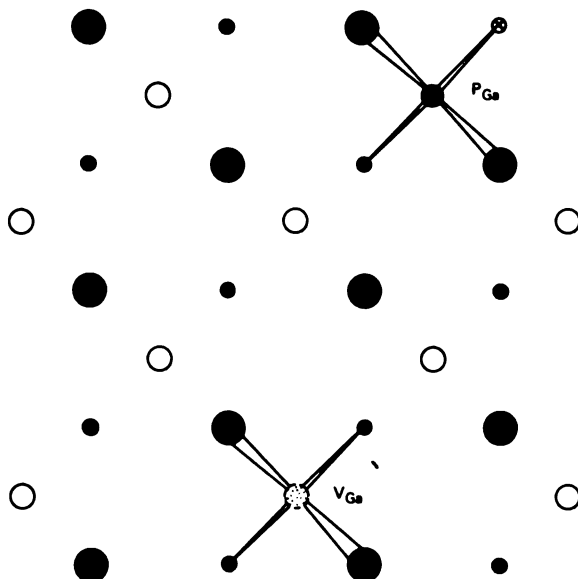


Figure 10. The defect structures as seen from a [001] direction in the III-V GaP lattice. Two planes of P atoms (solid circles) with the intervening plane of Ga atoms (open circles) are shown. In the upper right is the $\text{P}_{\text{Ga}} - \text{P}_3\text{X}$ antisite-impurity defect and in the lower center the V_{Ga} vacancy.

Once the identification has been made, much more information about the Ga vacancy can be obtained. The vacancy is stable at room temperature. It acts as an electron trap which exhibits the EPR when in the double-negative charge state. Its energy level lies near the center of the band-gap. Finally, the production rate for 2-MeV electron irradiation is much higher in p-type starting material than in n-type.

For n-type GaP, a different EPR spectrum and thus a different defect is observed after moderate irradiation (Figure 11). Again, hyperfine splittings are apparent. The data show a pair of widely split absorptions, with each partially split in an identical way into four lines. In this case, the spectrum is isotropic, which means that the sp^3 bonding is complete at this defect. The large splitting is attributed to the hyperfine field produced when a P atom is located at the center of symmetry of the defect. The smaller partial splittings indicate that three P atoms are the neighbors nearest to the central P atom. Thus, the defect structure is an antisite, a P atom on a Ga site, surrounded by three P atoms and one substitutional impurity. The $\text{P}_{\text{Ga}} - \text{P}_3\text{X}$ structure is illustrated in Figure 10.

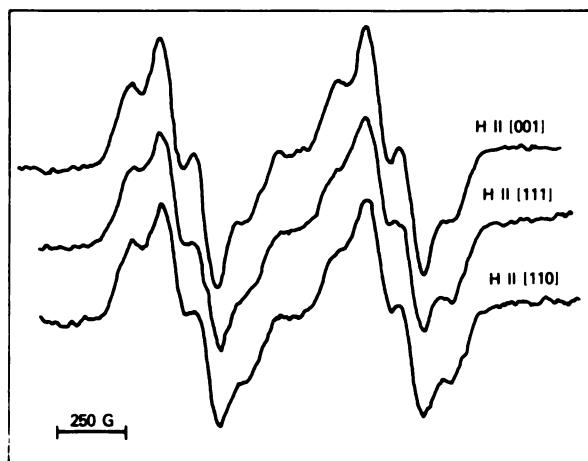


Figure 11. EPR absorption derivative spectra at 24.37 GHz for electron-irradiated n-type GaP. Data for three magnetic field directions in the (110) plane are shown.

Although antisites cannot exist in the single-element semiconductors Si and Ge, they should be particularly important defects in III-V compounds. The difference in electronegativity between the constituent atoms is small, and anion-cation substitution is expected to take place easily. The present identification of the $P-P_3X$ center at NRL, and work by others on the $P-P_4$ center, confirm that antisites do indeed exist in the III-V semiconductors.

The Ga vacancy and the $P-P_3X$ center are the first radiation-induced defect structures in a III-V semiconductor to be identified. Progress is being made toward a complete understanding of these defects, which will allow the production of more nearly perfect and more radiation-hard III-V materials for Navy electronics applications.

[Sponsored by ONR]

Nondestructive Evaluation of Structural Defects, by M. Fatemi and B. B. Rath, *Material Science and Technology Division*

The potential advantages of using neutrons to evaluate structural defects in materials have been recognized for many years. However, the full examination of these potentials has awaited the recent availability of high cold-neutron fluxes, monochromatization, collimation, and detection technology.

Cold and thermal neutrons can penetrate to depths 1000 to 10000 times greater than x

rays of comparable wavelength without being affected by multiple Bragg scattering from a crystalline lattice. Thus, their scattering behavior at small angles can be used to systematically characterize materials' defects varying in size from 2 to 500 nm (20 to 5000 Å). Furthermore, the distinctly different neutron-scattering cross sections from neighboring atomic-number elements allow experiments which can evaluate nonhomogeneous distributions of solutes in metals and alloys. Flaws in engineering materials include voids, microcracks, precipitates, and inclusions, which form during fabrication processes such as powder consolidation, super plastic deformation, cold forming, shaping, welding, plasma spraying, and diffusion bonding. In addition, damage occurs during service use from fatigue, creep, environment-induced corrosion and embrittlement, and stress- and temperature-assisted precipitation. These service-limiting flaws can now be nondestructively characterized by small-angle neutron-scattering (SANS) methods.

NRL scientists, making use of the reactor and the SANS facility at the National Bureau of Standards, Gaithersburg, Md; have recently begun a comprehensive program to characterize and quantitatively evaluate (a) nucleation and growth of voids during high-temperature creep at various strains and strain rates, (b) formation of microcracks during static and dynamic loading, (c) kinetics of stress- and temperature-induced precipitation in high-temperature alloys and ceramics, and (d) thermodynamics and kinetics of solid-state crystallization of metallic glasses.

Since long-wavelength neutrons scatter at small angles in a manner similar to x rays, the well-developed formalisms developed by workers in x-ray scattering can be applied. Relevant information about the shape, size distribution, and volume fraction of defects can be obtained from two basic experimental parameters: the scattering angle and the intensity of scattered neutrons.

The SANS spectrometer assembly is shown schematically in Figure 12. The spectrometer consists of several neutron filters and collimation systems used to obtain a well-defined beam profile and a velocity selector used to provide a preselected wavelength with a λ resolution of 20% (λ ranging between 0.45 and

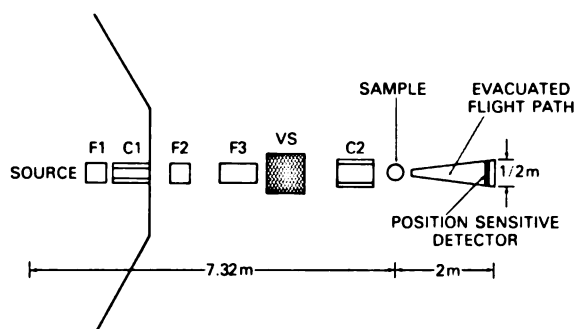


Figure 12. Schematic of the SANS spectrometer at the NBS reactor showing the order of collimators (C), filters (F), and the velocity selector (VS)

1 nm (4.5 and 10 Å). After being scattered in the sample, the beam travels through a 2-m evacuated flight path to a position-sensitive detector which has 500 channels covering ~ 10 min to ~ 7 degrees of arc in scattering angle. The data are automatically compiled and are subsequently reduced by the use of an appropriate algorithm to provide a graphic display of the scattering profile from a given sample.

Studies have been initiated to examine the crystallization behavior of amorphous metals. Binary amorphous alloy (Metglass BNi-6; Ni-11P-0.1C) was examined in the amorphous and the almost fully crystallized states. X-ray diffraction spectra of the alloy in these two states have been examined. The amorphous material displays the characteristic broad diffraction ring, whereas the annealed material indicates the presence of nickel and nickel phosphide crystals. The crystallization process clearly suggests the nucleation and growth of Ni_3P and Ni crystallites from the amorphous matrix. The neutron-scattering profiles of the crystallized and amorphous alloys are significantly different (Figure 13). The difference in the scattered intensity is related to the size of the microcrystallite and its density.

Preliminary results of another study are shown in Figure 14. Nichrome V rods (80Ni-20Cr) were subjected to creep at 810°C to fracture, under stress conditions ranging from 29 to 41 MPa. The scattered intensities from these samples, normalized to a control not subject to creep, reveal that the number of voids continues to increase in all size ranges with decreasing stress and consequently with increasing time to fracture. This observation is consistent with

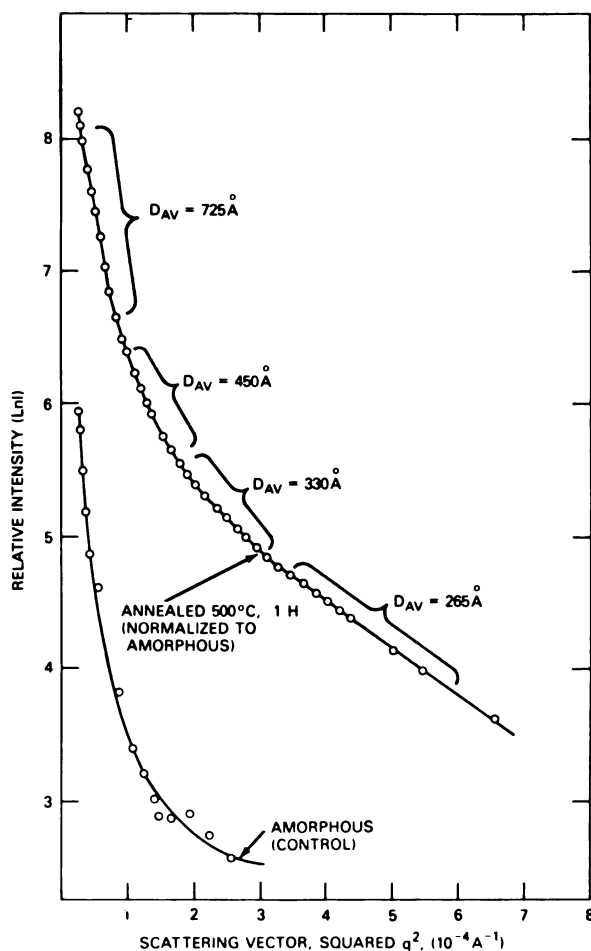


Figure 13. Guinier plot of scattered neutron intensity from amorphous and annealed Metglass BNi-6. In the Guinier plot, the natural log of the relative intensity is normally plotted vs the square of the scattering vector q , where q is simply related to the angle at which the scattered intensity is recorded ($q = (4\pi/\lambda) \sin \theta$). The average size, D_{av} , of the scattering particles and voids is derived from the slope of the curve segment indicated.

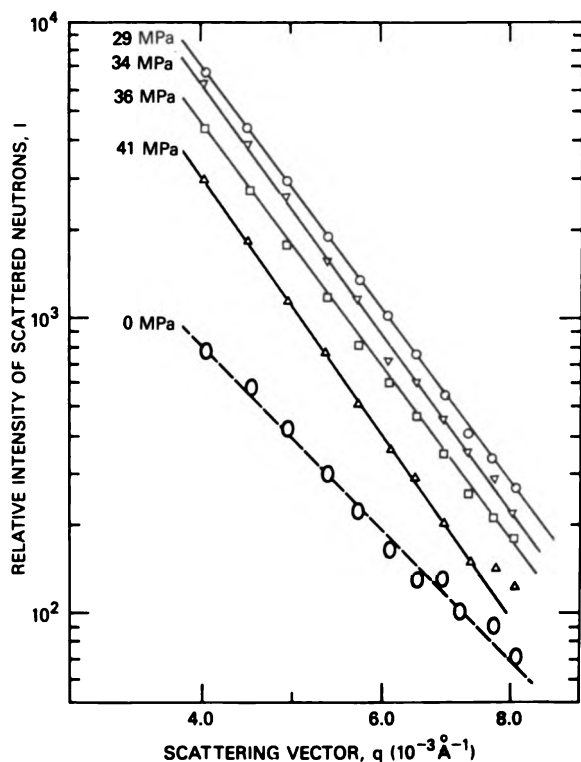


Figure 14. SANS intensity profiles of creep-induced voids in Nichrome V. Each profile is fitted to data points from a sample that has been subjected to high-temperature (810°C) creep to fracture. The higher the relative intensity, the larger the number of voids produced by the indicated stress. Note that intensities vary inversely with stress. The curves for the stressed samples were normalized to the unfatigued (without voids) sample (dashed line).

the hypothesis that vacancy diffusion controls void nucleation and growth in this material.

Results of these preliminary studies and others now under way will be analyzed to establish the utility of SANS as a diagnostic tool to optimize processing variables as well as to predict the service life of engineering alloys and ceramics.

[Sponsored by ONR]

Spectral Diagnostics of X-Ray Simulators, by C. M. Dozier, D. B. Brown, and J. W. Criss, Radiation Technology Division

The vulnerability of electronic components and systems to x and γ radiations can be tested by either steady-state (continuous) or pulsed x-ray sources. Some aspects of this vulnerability to nuclear weapon radiation can be tested best by pulsed x-ray simulators. In

either case the simulator's x-ray spectral distributions must be known accurately for effective data interpretation.

Measuring the spectral distributions of pulsed sources requires experiments which are both time consuming and costly. Furthermore, diagnostic instrumentation occupies valuable irradiation space and can interfere with test measurements. Calculation of the spectral distributions using Monte Carlo codes offers an alternative to experimental measurements, but such calculations are not routinely made because the codes are costly to run.

As a consequence, many simulators have little or no spectral distribution data available. Those simulators with known spectral distributions typically have measurements or calculations for only a limited number of operating conditions (e.g. voltage, current, target geometries) and target materials. These constraints limit the effectiveness of vulnerability testing by the experimenter. In addition, the limited spectral information cannot account for shot-to-shot variations occurring in the simulators.

NRL's researchers have applied their experience in measuring and calculating spectral distributions for steady-state x-ray tubes to the determination of spectral distributions of pulsed x-ray simulators. This effort has produced a convenient, inexpensive method for calculating accurately the spectral distribution of pulsed simulators.

The calculation requires measurements of the current and voltage pulses applied to the simulator diode. Normally, these two measurements are recorded for each shot and do not require additional instrumentation or irradiation space. An inexpensive x-ray generation code is used to calculate the spectral contribution for each voltage and current increment during the pulse. The required accuracy is maintained by automatically scaling these inexpensive calculations to a few more complex and more accurate x-ray production calculations. Both time-resolved and time-integrated spectra can be obtained from the calculations for each time interval during the pulse. Generally, the calculated time-integrated spectra have agreed with experimentally measured spectra to within 20%.

Figure 15 shows calculated and measured spectral distributions for large and small pulsed

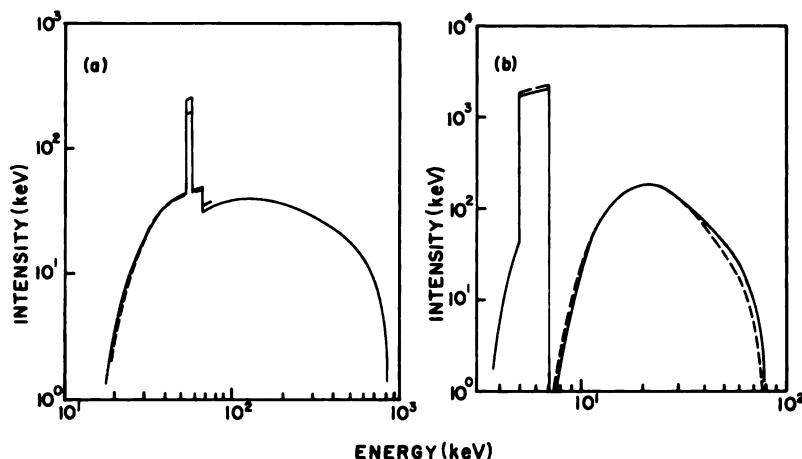


Figure 15. Comparison of calculated (solid curve) and measured (dashed curve) spectral distributions for a large (a) and small (b) pulsed x-ray source with different operating conditions. (a) Spectrum from a 0.005-cm-thick tantalum target at 1 MV; (b) spectrum from a 0.0025-cm-thick iron target at 100 kV. In both cases, calculations agreed to within 20% of experimental results.

x-ray sources with different operating conditions. Figure 15(a) shows the spectra measured (to 80 keV) and calculated for a single shot. This shot was made using a 0.005-cm-thick Ta transmission target on a 1-MV pulsed x-ray source. The calculations agreed with the measurements (obtained with a LiF curved-crystal spectrograph) to within 10 to 15% for this shot and also provided the spectral distribution at energies beyond the range of the spectrograph.

Figure 15(b) shows measured and calculated spectral distributions for a small 200-kV pulsed source with a 0.0025-cm-thick Fe transmission target and a pulse length of 0.5 μ s. Active detectors behind balanced filters looking at fluorescers were used to measure the complete spectral distributions. In this experiment the calculations agreed with the measurements within 20%.

The shot-by-shot spectra made available with this new calculational method permit the optimization of testing programs and more reliable interpretations of test results. Better depth vs dose distributions in electronic components as well as the dose in adjacent components of widely differing atomic masses can readily be obtained. In addition, secondary radiation processes can be examined with greater accuracy. Finally, the most useful application of the calculational method may be to assist in the selection of target materials and simulator operating

parameters that optimize the testing of varied electronic components and systems for military application.

[Sponsored by ONR]

Neutrino Astronomy by Deep-Ocean Detection, by M. M. Shapiro and R. Silberberg, *Laboratory for Cosmic Ray Physics*

NRL physicists are participating in opening up the emerging field of neutrino astronomy. Celestial sources of neutrinos can be detected and studied by using underwater detectors sensitive to Cerenkov light and acoustic signals that result from collisions of neutrinos with atomic nuclei in water molecules. A consortium of laboratories, with participants from universities as well as NRL, is planning and designing a Deep Underwater Muon and Neutrino Detector (DUMAND).

The prospect of detecting discrete celestial sources of neutrinos depends in part on the nature and intensity of the *background* of diffuse neutrinos. The principal sources of this background are expected to be the Earth's atmosphere and the Galaxy. The neutrinos from both sources are produced by interaction of cosmic rays with matter. As part of an investigation of the radiation environment at great ocean depths, and in collaboration with NASA researchers, NRL has estimated the neutrino luminosities of the Earth's atmosphere

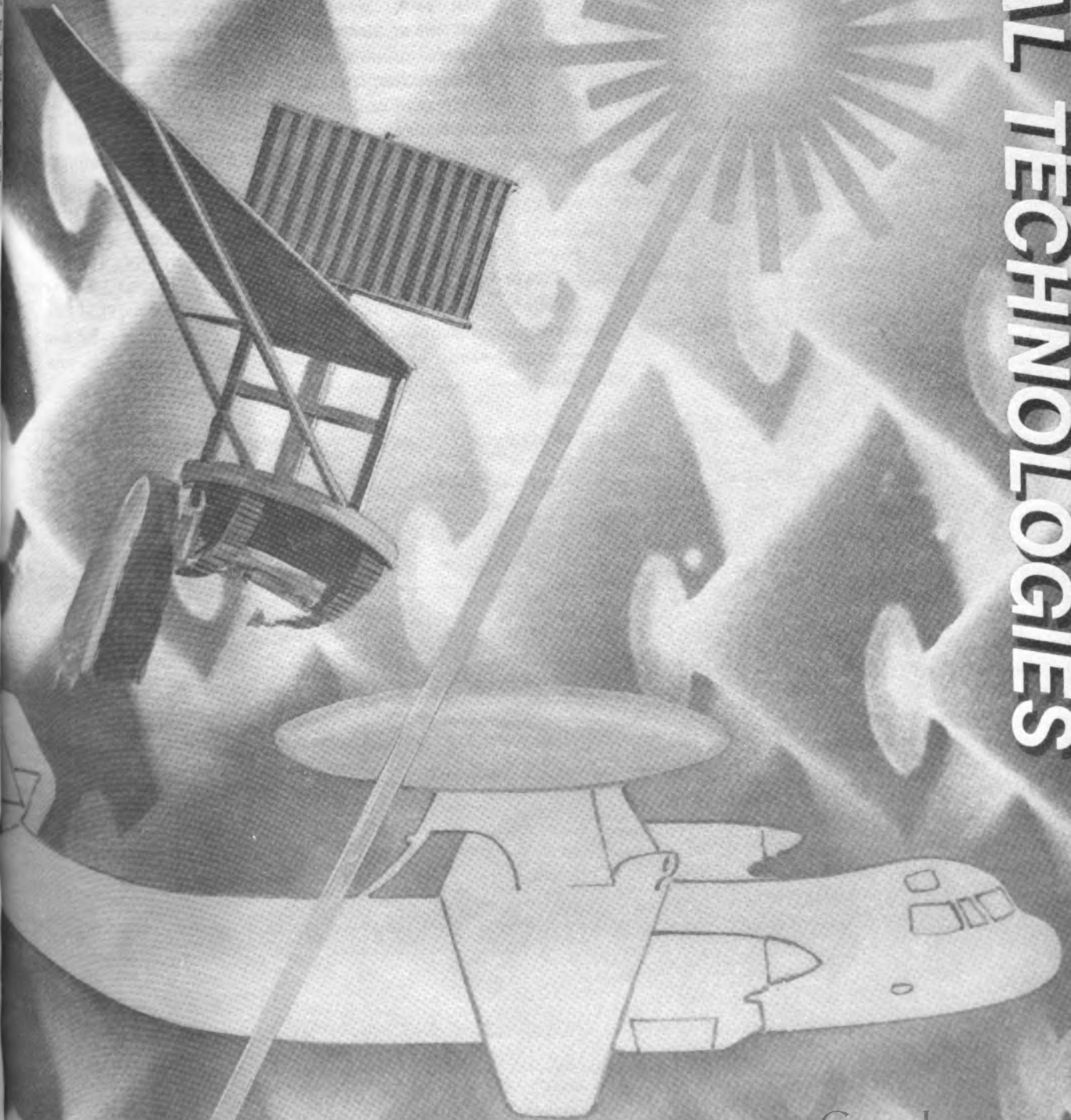
and of the Galaxy. Neutrinos entering the ocean with energies exceeding 10^{13} eV generate cascades containing hundreds of pi mesons and thousands of electrons and positrons. Each of these produces along its path a column of ions and a flash of blue-violet Cerenkov radiation that lights up the dark ocean depths. It is estimated that the radiation can be observed as far away as 40 m. More energetic neutrinos, those above 10^{15} eV, generate even longer, tightly collimated cascades that heat up a column of water, producing a pressure pulse that should be detectable as an acoustic signal from roughly 1 km away. About 40 000 neutrino interactions at energies above 10^{12} eV are expected per km^3 of water each year. Neutri-

nos with lower energies are more abundant. For example, the number of neutrino interactions at energies above 10^9 eV is expected to be on the order of 40 000 000 per km^3 each year.

Large numbers of neutrinos are expected from stellar collapse and associated explosions—the supernovas—and from active galactic nuclei like those in radio galaxies, Seyfert galaxies, and quasars. The energy output of one of these sources in 1 s is equivalent to the total energy released by about 100 billion billion hydrogen bombs. Neutrinos generated by high-energy nuclear interactions in such objects can tell us much about the nature and processes of these powerful sources of energy.

[Sponsored by ONR]

ELECTRONIC & OPTICAL TECHNOLOGIES



ELECTRONIC AND OPTICAL TECHNOLOGIES

A fleet without its modern electronic and optical capabilities—without the detection, fire-control, intelligence-collection, and information-handling capabilities afforded by radar, infrared, and a host of other electronic and optical devices—would surely be helpless in today's world. Since its beginning, more than fifty years ago, NRL has made many important contributions to these essential areas, and Laboratory scientists and engineers continue to break new ground in searching for innovative and improved ways to perform these vital functions.

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Field Emission Array Cathodes for High-Power Microwave Tubes, by H. F. Gray, *Electronics Technology Division*

The Navy needs electron emitters that turn on immediately after long shelf storage for use in high-power microwave tubes (e.g., traveling wave tubes used for expendable decoys and seekers). Today, microwave tubes use thermionic cathodes for electron emitters. Thermionic cathodes, however, have several limitations: (a) they do not turn on reliably after a reasonable shelf storage time; (b) they do not turn on immediately because of the time required to heat up the heater and cathode material; (c) they do not turn on fully until their surfaces reactivate (*i.e.*, until the work function has lowered to its operating value); and (d) they require heaters which are prone to fail and heater power supplies which are heavy and bulky. Field emission cathodes, which consist of large area, low voltage, field emission arrays (FEAs) should circumvent all of these

problems. First, the FEAs should turn on reliably after long shelf storage because there will be no thermal outgassing of the cathodes and other tube parts associated with thermionic cathodes (e.g., heaters and cathode assemblies). Second, the FEAs should turn on immediately because the emission is purely electrostatic. Third, the FEAs should turn on fully because no surface activation is required. Fourth, there are no heaters or heater power supplies to contend with.

NRL is developing a new FEA technology using standard silicon processing techniques found throughout the microelectronics industry. In fact, using orientation-dependent etching of silicon $\langle 100 \rangle$ surfaces, such as that used to make vertical metal-oxide-silicon (VMOS) transistors, NRL has fabricated arrays of very sharply pointed, single crystal silicon field emitters such as that shown in Figure 1. In this scanning electron microscope picture, the formation process of the silicon emitter cones has been

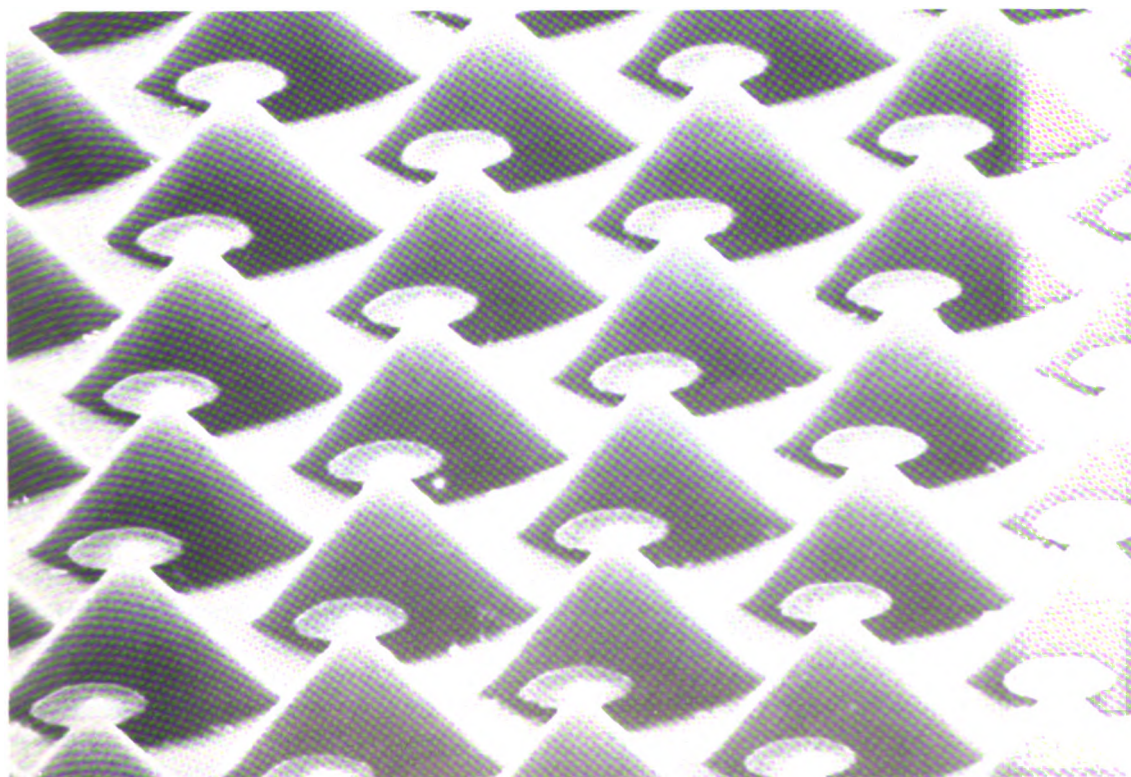


Figure 1. Scanning electron microscope picture showing the field emitter cones created by orientation-dependent (anisotropic) etching of the silicon $\langle 100 \rangle$ surface. The round discs (SiO_2) on top of the cones define both the size and location of the cones. The process has been stopped before the sharp tips are formed. 10 000 X.

stopped to show the circular SiO₂ masking pads on top of the cones. These masking pads, in fact, define the size and location of each field emitter cone. As the etching proceeds, the cones are crystallographically etched to sharp points at which time the SiO₂ masking pads fall off. Figure 2 is a "Fowler Nordheim" plot of electron emission as a function of applied extraction voltage for such a "nude" FEA. In this type of plot, field emission is characterized by a straight line, so it is clear that the electron emission for our FEA is produced by the electrostatic field impressed on the sharp tips of the cones.

To make low-voltage FEAs, an insulating SiO₂ layer approximately 1.5 μm thick is deposited from a chemical vapor onto the "nude" arrays, after which a 0.5- μm layer of metal (*e.g.*, gold or aluminum) is evaporated over the insulator to form a closely spaced electron extraction electrode. Etching of this MOS-type sandwich structure produces the FEA device shown in the scanning electron microscope picture in Figure 3. This particular device is a silicon FEA with gold metallization (for reliability) made at NRL. As a result of the particular deposition and etching processes used, the holes align themselves over the emitter cones (self-alignment), thereby producing the symmetric emitting structure seen in Figure 3. The

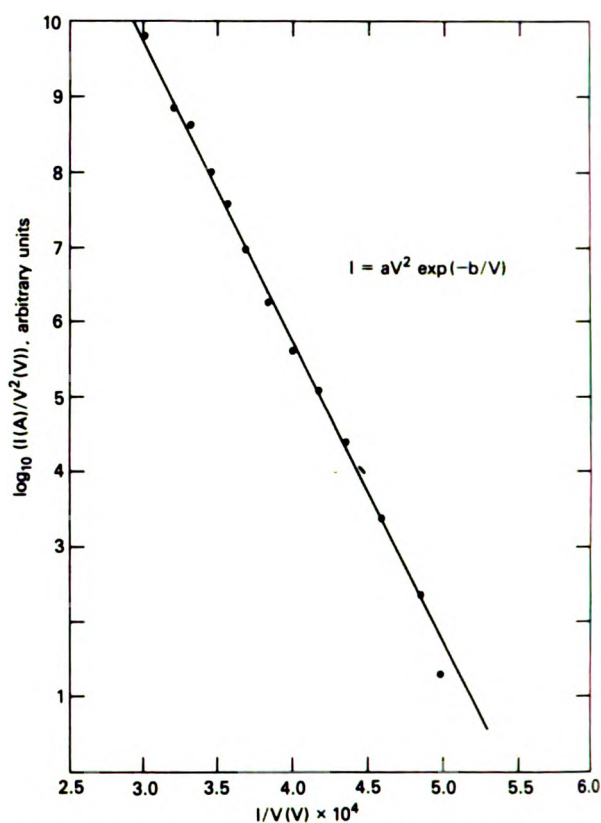


Figure 2. Field electron emission as a function of applied extraction voltage for an array of "nude" emitter cones such as would be obtained from completion of etching in Figure 1. This "Fowler-Nordheim" plot confirms that the observed current is field emission.

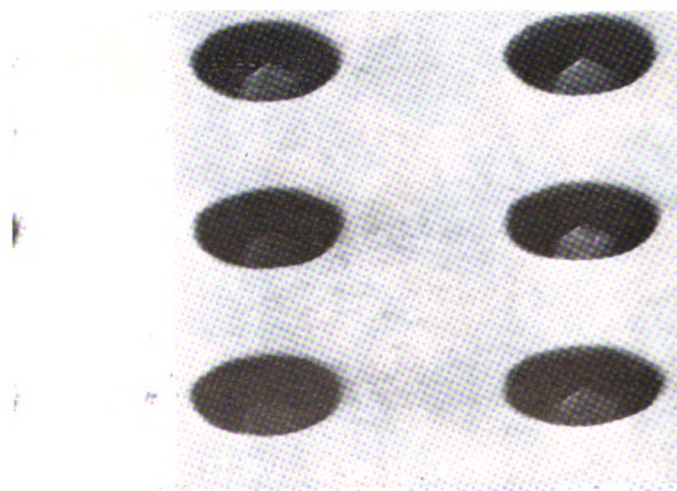


Figure 3. A self-aligned, monolithic, FEA sandwich structure with integral extraction electrode fabricated at NRL using standard silicon microelectronics processing (photolithography, wet etching, etc.). The dimensions of this device are: (a) emitter-to-emitter spacing is 10 μm ; (b) aperture hole size is 2 μm ; and (c) emitter radii are approximately 300 $\text{\AA}$.

emitter-to-emitter spacing in this device is 10 μm , which gives an emitter density of $10^6/\text{cm}^2$. The current from a single field emitter (such as those used in electron microscopes), is normally in the 10 to 100 μA range. Consequently, if each tip emitted only 10 μA , the FEA cathode would furnish a current density of 10 A/cm^2 , which is higher than thermionic cathodes can provide with reasonable life expectancy. Furthermore, this device does not represent the state of the art, and the packing density can be increased quite easily over that shown here by using only standard silicon microelectronics processing techniques.

The primary advantage of this NRL-developed technology is that standard silicon microelectronics processing techniques can be used to make closely spaced sandwich structures. These MOS structures permit the use of low voltages to excite and control the electron emission process, thereby promising a reliable cathode in normal microwave tube environments. This new cathode type promises to circumvent many of the problems experienced with thermionic cathodes used in high-power microwave tubes that must be stored for long periods of time. Furthermore, low-voltage beam modulation appears to be feasible along with immediate turn-on characteristics, thereby permitting the development of new microwave generators having better performance and greater flexibility.

[Sponsored by ONR]

Use of SQUIDS on Moving Platforms, by J. H. Claassen, *Electronics Technology Division*

The most sensitive magnetic field detectors now known make use of the unique properties of superconductors. These devices, known as SQUIDS (Superconducting Quantum Interference Device), presently have sensitivities of $\sim 10^{-14}$ tesla per root Hertz and their projected performance shows that significant further improvements will be possible. Several Navy systems, including low-frequency communications antennas and magnetic anomaly detection systems, would benefit from improved magnetic field sensitivity.

In operational applications, the sensors would be mounted in a platform, and towed either underwater or in the air. There are lim-

its to the stability that can be obtained in such platforms, particularly in the airborne case. Since SQUIDS sense the vector components of the magnetic field, the existence of even very small fluctuations in platform orientation relative to the Earth's magnetic field ($\sim 5 \times 10^{-5} \text{ T}$) will generate large spurious signals. To keep these rotation-induced signals below the intrinsic noise of the sensor itself would require a platform stability and pointing accuracy better than 10^{-7} rad, which is far beyond present capabilities.

NRL has explored an alternative approach that entails the use of three SQUIDS oriented orthogonal to one another. The advantage of this arrangement is that the sum of the squares of the three field components will not be affected by platform rotations. A SQUID magnetometer, however, measures only the *changes* that occur in a field component after the instrument is switched on (the initial reading always being zero). Hence, there is an unknown offset—the value of the actual initial field—that must be added to each channel before squaring and adding, and this offset will be different each time the system is activated.

It has been shown at NRL and elsewhere that a sequence of SQUID readings for various (random) platform orientations contains sufficient information to deduce these offsets. Two general types of algorithms have been proposed to accomplish this: a least squares minimization of an appropriate, linearized error function; and a continuously operating adaptive updating of a set of trial offsets. Both of these were shown to work under somewhat idealized circumstances.

A recent NRL study investigated the performance of these algorithms under more realistic conditions and developed refined versions better suited to the anticipated operational conditions. Several complicating factors that had previously been ignored were explicitly considered and found to critically affect the overall success of any algorithm. The first of these factors is the presence of low-frequency fluctuations in the magnetic field due to such causes as far-away thunderstorms. In trying to adjust for these fluctuations, any algorithm will compute slightly erroneous values for the SQUID offsets. These errors, in turn, contribute to errors in the output of the processing system,

which ideally should duplicate the changes in total field that occurred (whether due to "signals" or random fluctuations) after the system was turned on. Hence, an important figure of merit of an algorithm is the "processing noise" induced by it in response to external noise fluctuations. This was studied by computer simulation, and typical results are shown in Figure 4. In this case, the external noise is assumed to be highly correlated in time (as it typically is in real life) with a power spectral density (PSD) inversely proportional to the square of the frequency. The most successful algorithm for this type of external noise was a version of the least squares approach, with the results shown in Figure 4. A certain delay, or acquisition time, T , is required after the system is turned on before enough data have accumulated to make an accurate estimate of the offset parameters. This provides a convenient reference time, and the reader will note that frequency is plotted in units of inverse acquisition time T^{-1} in Figure 4.

An important insight from this study was the significance of the characteristic correlation time τ_R over which the platform orientation

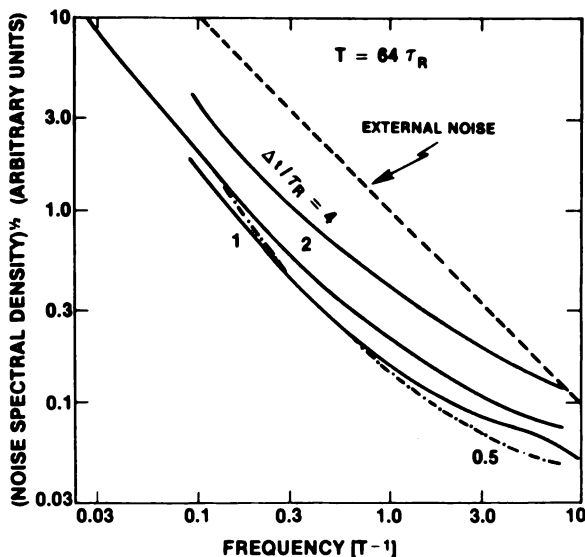


Figure 4. The equivalent magnetic field noise that results from the signal processing is shown for the most successful algorithm studied. This noise is scaled with the ambient external field noise (dashed line) which has a power spectral density $\sim (\text{frequency})^{-2}$ in this example. The acquisition time T , sampling interval Δt , and platform correlation time τ_R are defined in the text.

remains relatively constant. The signal is sampled at intervals of Δt , and the length of the interval relative to τ_R affects the PSD of the processor output errors. The best results (see Figure 4) are obtained with Δt smaller than τ_R , but even with much larger sampling intervals, the processing errors are comfortably below the external noise level at all frequencies. It was found that when the platform orientations are significantly correlated during the acquisition period (i.e., $\tau_R > T$), the processing errors are approximately equal to the external fluctuations, no matter how many samples are taken.

Another complication that was considered is the fact that a moving system sees a uniformly changing total field due to gradients in the Earth's field. It was found that a least squares algorithm could easily be modified to deal with this situation, but adaptive approaches ran into serious problems.

These computer simulation studies have explored the feasibility of obtaining significantly improved sensitivity in magnetic field detection by using SQUIDs as the primary sensors. A figure of merit, the "processing noise," was developed to evaluate various algorithms which could be used to extract magnetic field information from the raw SQUID data. With realistic operational conditions, the simulations identified a least squares version as the best choice and an optimized version was developed. Although unanswered questions remain about the availability of platforms with sufficiently small oscillations and the ability to obtain digitized SQUID outputs with adequate dynamic range, this study found no unsurmountable difficulties in sight. The next stage in the development of this technology should be testing of a simple prototype system using the developed algorithms.

[Sponsored by JHU/APL]

A Small-Scale Electronic Warfare Simulator,
by R. E. Surratt, *Tactical Electronic Warfare Division*

The Central Target Simulator Auxiliary Chamber (CTSAC) is a small-scale hardware-in-the-loop simulation laboratory designed to evaluate EW systems and techniques. This laboratory is being used to support the overall development effort for the NRL Central Target

Simulator (CTS) facility. The facility is being developed to conduct large-scale simulations of tactical scenarios in which antishipping capable missiles (ASCM) attack a single or multiship task force using electronic countermeasures (ECM) as part of its defensive tactics. The CTSAC is configured to respond to the needs of this overall CTS effort by using a variety of standard special test instrumentations. The system can perform real-time closed-loop ASCM/ECM simulations. The CTSAC includes a specially designed shielded anechoic chamber with a matrix of phased antennas directly coupled to the CTS facility's distributed multiprocessor network.

In addition to its support role, the CTSAC is designed to provide users with a powerful tool for solving a wide range of ECM related problems. The system incorporates a combination of digital computers, RF hardware, digital hardware, and software, to generate a controlled RF environment in an anechoic test chamber with the following characteristics. The chamber is 7.0 by 3.8 by 4.6 m with access doors at both ends and a 4.6 m radius of curvature from focal point to array. It is lined with Emerson and Cuming 0.2 m pyramidal (VHP-8) absorber material and has 36 dB isolation in a cubic quiet zone 0.6 m on a side. With modification, the CTSAC can be used for problems requiring: (a) evaluation of ECM tech-

niques; (b) real-time simulation of ASCM with RF guidance hardware-in-the-loop; and (c) real-time simulation of complex target characteristics (scintillation, glint, multipath, clutter, etc.). CTSAC allows the user complete control of the key parameters and enables him to gather a statistical data base to evaluate ECM effectiveness and resolve differences between field test results and analytical models.

The hardware components of the CTSAC, depicted in Figure 5, can be used to simulate a wide range of target and threat types. The array operates either in a pulsed or CW mode and features fast switching speed, which allows multiple targets and/or ECM returns to be simulated. Each target parameter, position, return amplitude, time delay, etc., can be varied independently. Very high angular velocities can be simulated, and any point on the array is addressable during the interval between two pulses. Thus, the simulation of difficult situations such as distributed targets with angular glint can be generated. A basic angular resolution of 1 mrad is achievable for any target motion. These characteristics, along with the simulation parameters shown in Table 1, allow very accurate target modeling and highly versatile scenario generation to be achieved.

Applications software development for CTSAC has progressed along the lines of simulating a generalized RF guided missile/ECM

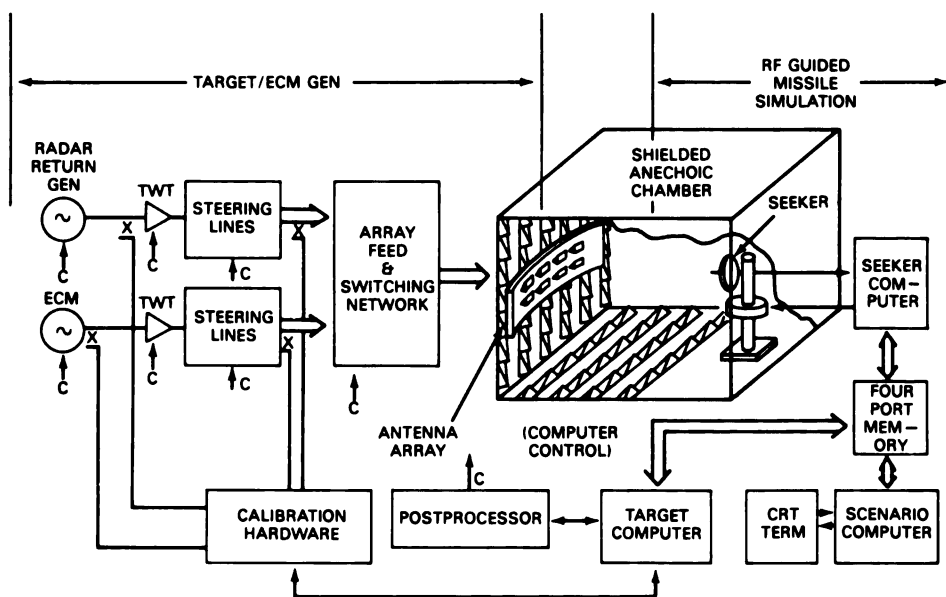


Figure 5. CTSAC hardware block diagram

Table 1
CTSAC Simulation Parameters

Parameter	Present	Future
Frequency	8-18 GHz	Same
Scenario coverage	13.4° az. × 1.9° el.	24.8 ° az. × 5.7° el.
Polarization	Linear (hor., vert.)	Arbitrary
ERP	+23 dBm (Space loss 64 dB at 8 GHz)	+51 dBm
Dynamic range (Target cross-section seeker pattern, range scintillation)	100 dB	Same
RF mode of operation	CW, pulse, fixed frequency	Frequency agile
Receive capability	No	Yes
Target capabilities	6 multiple targets with 2 simultaneous time and/or space coincident targets	10 multiple targets with 2 to 4 simultaneous time and/or space coincident targets
Target angular Location accuracy (Instantaneous)	1 mrad	Same
Target angular rate	60°/s (2 mrad steps)	Same
Range delay	80 km	160 km
Seeker size	HPBW of less than 5° requires near- field correction	Same

encounter. Missile models which will be implemented into the CTSAC system feature an all-digital approach for simulating missile guidance, dynamics, and kinematics. This approach provides the CTSAC with several distinct advantages, which include (a) repeatability of runs, (b) dynamic range of simulation parameters, (c) ease of model modification, and (d) availability of equipment and maintenance.

At present, CTSAC is running a bank-to-turn missile model at a 16-ms update rate. A recently developed cruciform missile model is also available. Missile specific data for both types are organized to minimize transition development.

Three PDP-11/55 computers are coupled through a common four-port memory which allows two-way communication between the

three. The scenario computer defines the scenario in real time and performs coordinate transformations between the seeker and target coordinate systems. The seeker computer digitally emulates the seeker autopilot and missile flight dynamics functions while driving the azimuth positioner holding the seeker. The target computer performs calibration of all target generation equipment to ensure accurate target representation and positioning. During real-time operation, the target computer calculates the "center of gravity" equations, calibration corrections, and near-field corrections for each target return and ECM source. The information is then transferred to the postprocessor, a fixed-program digital processor, which performs timing- and drive-signal correlation for both the seeker and target generation equipment during real-time operation.

The CTSAC has proved to be a valuable aid in developing design concept for the CTS, and has developed in capability to the point where closed-loop missile/ECM simulation work can be performed.

[Sponsored by ONR]

A Digital Data Acquisition System, by D. S. Woodson III, S. Ceravolo, and C. B. Brookes, *Tactical Electronic Warfare Division*

The problem of evaluating shipboard electronic warfare (EW) systems in an operational environment has led NRL engineers to develop a compact digital data acquisition system (DAS II). Its purpose is to provide the Navy with a technique for evaluating the fleet's ability to counter missiles that use RF electronic guidance. This system has improved digital signal-processing and recording capabilities as compared to earlier analog techniques used in development of the DAS I. The DAS I proved the concept of multiplexing and recording radar signals for use to evaluate electronic countermeasure (ECM) effectiveness.

The DAS II is designed to record and reproduce radar video signals and other pertinent data from airborne missile-guidance simulators. For example, it will digitize and interlace radar video and other key parameters from a fleet EW support group (FEWSG) pod simulator system with the video from a search

radar and various aircraft parameters. When shipboard ECM systems are being tested, the system is flown, and data are gathered under field conditions. These data provide the information necessary to evaluate the effectiveness of shipboard ECM techniques and system operations. This evaluation compares the recorded data with results obtained previously from laboratory digital models and is used in the development of improved countermeasure techniques.

The flexibility of the DAS II system comes from its ability to accommodate several operational pods, each containing a separate and distinct radar seeker operating over X and Ku frequency bands. Previous testing has relied almost entirely on verbal reports of the electronic warfare officer (EWO) with occasional backup from cameras directed toward the target ship or the simulator's associated scope presentation. Unfortunately, sometimes the errors induced by electronic countermeasures and decoys are too subtle to be identified by those methods. The DAS II system provides the data collection capability needed to ensure accurate data analysis and equipment evaluation.

Figure 6 is a conceptual illustration of how the DAS II operates. The DAS II consists of two separate subsystems for airborne and ground data. The airborne data-collection subsystem provides real-time display and analysis to the EWO during an airborne mission. A parallel operation which encodes and records serial data on a high-density digital recorder is used to reproduce detailed events. The ground-data-reproduction subsystem provides a duplicate of the airborne PPI display, interlaced search radar and simulator radar video, and additional buffered outputs for use on the ground by an EW mission analyst. LED (light emitting diode) and DPM (data processing machine) console displays provide selectable readouts from either radar system or aircraft parameters for postmission analysis. Analog outputs are provided for strip chart recorders which allow a quick look at simulator parameter data, and digital outputs provide a means to correlate field data with previous laboratory data for statistical analysis.

During the airborne mission the EWO operates the radar and data collection equipment, annotating his observations as the pilot

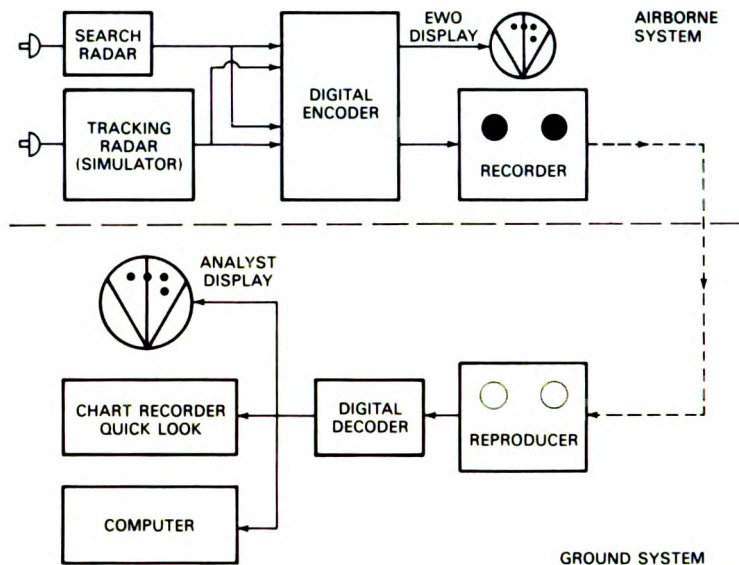


Figure 6. DAS II data acquisition system

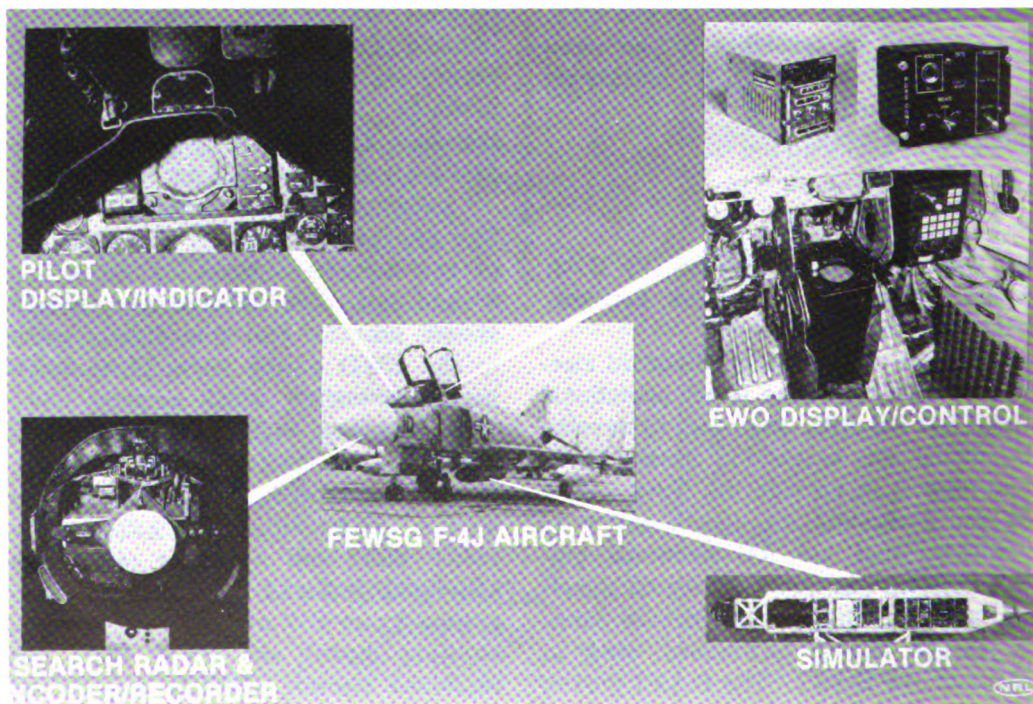


Figure 7. DAS II airborne system

flies a controlled course toward the ship. Outputs from the tracking radar are presented on a "heads up" display for the pilot to use in steering the aircraft. The airborne system (Figure 7) collects pulse-to-pulse data from two radar systems which cover a 20-nmi by 90° range/azimuth sector. In addition, data from

the air-data computers, the time-code information, and voice information are processed by the DAS II encoder. At present, the system handles two radar video signals, 20 discrete command/control type signals, 16 analog and 5 synchro aircraft parameters, and time code and voice information. All of these data are

encoded at an 8-megabit rate, assembled into a fixed format, and stored on a digital recorder, with the length of the frame word dependent on the pulse repetition frequency of the search radar.

An operational system has been developed and was installed on a fleet F-4J aircraft. This system was maintained by NRL engineers and operated for an extended period during technical and operational evaluations of the latest shipboard EW system (AN/SLQ-32). In addition to evaluating shipboard ECM systems and techniques, cooperative countermeasures with offboard decoys can also be accommodated. In this application, the DAS II provides reference coordinates with respect to the target in question and a projection of the total target scene available to the simulated missile. This information is used in correlating field data with analytical and laboratory data. Other applications of the operational system include ECM system operator training.

[Sponsored by NAVELECSYSCOM]

Reliability Improvements for Shipboard Radar Systems, by D. F. Hemenway, P. M. Thiebaud, and D. C. Cross, *Radar Division*

Methods and equipment are being developed to improve the reliability of shipboard radar systems. In one task area, called the Maintenance-Free Radar Program, computer-aided reliability/availability analyses have been used to define a preferred baseline system for a high-performance, two-dimensional air-search radar.

In a related task area, the Radar Reliability/Performance Improvement (RR/PI) Program is making reliability improvements in the radar data distribution system, which is the network of units carrying radar data from the radar to the indicators. A central part of this distribution system is the switchboard, which routes signals from the various radars to selected displays. NRL has developed a new solid state switchboard that is more reliable and less expensive than current electromechanical units.

The need for maintenance-free radar is driven by the increasing complexity of Navy radar systems and the fact that anticipated increases in performance have not always been realized because operational availability has not

kept pace. This lag is due primarily to personnel and logistics problems. It is very costly to train technicians in the necessary maintenance skills, and it is both difficult and costly to anticipate and provide the appropriate kinds of spare parts.

These problems would be minimal for a radar designed to operate maintenance-free throughout a ship's mission, *i.e.*, anywhere from 30 days to a year. This concept is feasible with today's solid state and digital technologies, whereas it would not have been possible earlier without impractical massive increases in equipment weight and space aboard ship.

By use of computer-aided reliability/availability analyses of a variety of hardware concepts, a preferred baseline system has been defined for a high-performance, two-dimensional, air-search shipboard radar possessing a mean-time-between-failure (MTBF) of more than a thousand hours. The program has investigated the modifications to this baseline system configuration that would be needed to assure a 90% probability of survival for unattended mission periods of 30, 90, and 365 days. The analysis results indicate that periods exceeding 5 months would require degrees of redundancy that are unreasonable from both system complexity and cost-effectiveness standpoints. However, over the baseline system, a 90-day unattended radar could be procured with increases of only 13% in acquisition cost (Figure 8) and 4% in weight.

Another critical area in shipboard radar concerns the radar data distribution system. An important component of this system is the switchboard which directs trigger, video (radar receiver), and synchro (azimuth angle) signals from the various radars to selected displays. Current switchboards employ electromechanical switches, which are unreliable, costly, and require regular overhauls every few years. An NRL-developed switchboard, which uses solid-state switches, is smaller, lighter, less costly, and more reliable than the currently installed units.

Figure 9 shows a comparison of the current radar data distribution system with the new one. In Figure 9(a), several radars are shown providing radar azimuth signals (*via* 5-wire synchro output), video signals, and synchronization triggers. Radar relative azimuth

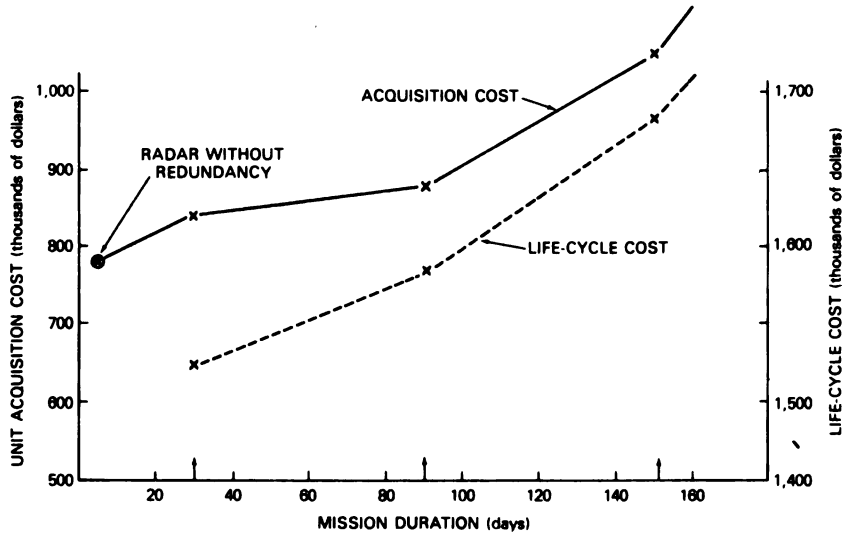


Figure 8. Cost vs mission duration for unattended radar

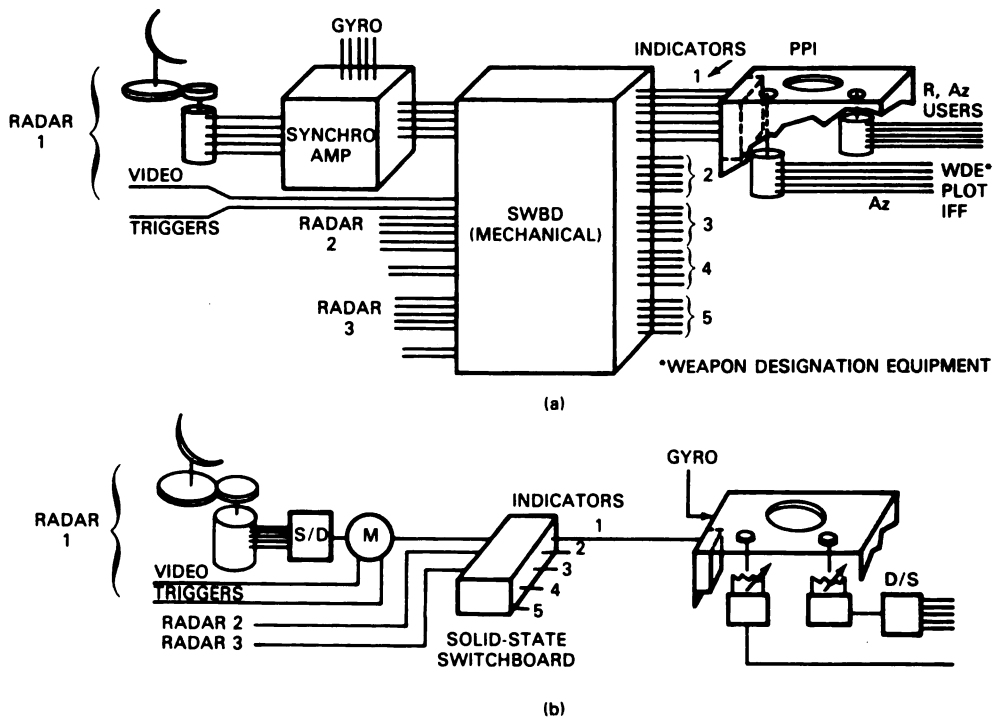


Figure 9. Radar data distribution systems: (a) current, (b) new

signals are combined with ship's absolute gyro heading angle to get a true azimuth angle input to the switchboard (relative to north). The switchboard allows switching of any of the input radars to any of a number of output indicators, which are generally plan position indicator (PPI) displays. Identification friend or foe

(IFF) signals (not shown in figure) are also switched with each radar input.

The simplification achievable with the new solid state switchboard is illustrated in Figure 9(b). In this new system, the radar relative-azimuth 5-wire synchro signals are converted (by a synchro-to-digital (S/D) con-

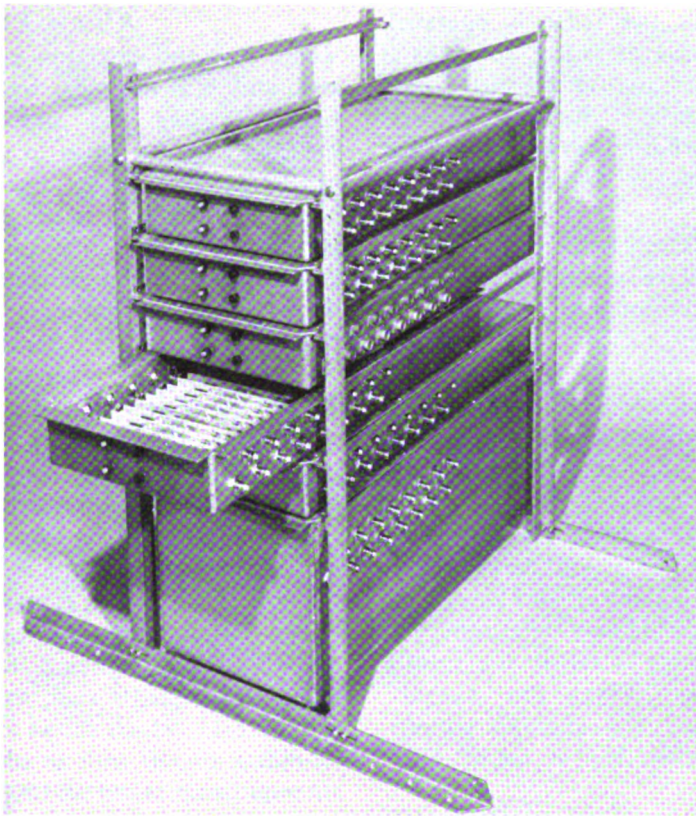


Figure 10. Advanced development model of new NRL solid state switchboard, 86 cm (34 in.) high, 30 cm (12 in.) wide, 76 cm (30 in.) deep as shown)

verter) to a simple 1-wire digital form and combined serially in the multiplexer for an output 1-wire signal to the relatively small digital switchboard. The cumbersome synchro amplifier of the current system (Figure 9(a)) has been eliminated, with the absolute ship's gyro heading angle being introduced in simple digital form directly at the indicators. Also, the range and azimuth data designated by an indicator operator (right side of figure) are provided to users by bulky 5-wire synchro outputs in the current system (Figure 9(a)), but in simpler single-wire digital form in the new system (Figure 9(b)).

An advanced development model (ADM) of the system, built at NRL, is shown in Figure 10 with the solid state switch cards exposed in one of the module drawers. Each level, or module, is dedicated to a specific function, with the top four modules handling only IFF. Each module has its own, redundant, power supplies for enhanced reliability. The bottom module,

which provides interface circuitry for the indicators, could be incorporated in the indicators themselves, thereby making the switchboard smaller, if desired.

Reliability-oriented programs of the types described can provide needed improvements in the operational availability of Navy shipboard radars. In many cases, the improvements can be achieved with only a modest increase in cost, as shown in the maintenance-free radar analysis, and, in some cases, such as the solid state switchboard, it is possible to achieve both increased reliability and cost savings.

[Sponsored by NAVMAT and NAVSEA-SYSCOM]

Radar Antenna Research, by T. L. ApRhys, W. F. Gabriel, and J. P. Shelton, *Radar Division*

The antenna remains a critical component in every radar system—it is the interface between the radar transmitter, receiver, processing, and display equipment and the physical

environment in which the radar is operated. Antenna research and development activities at NRL are carried out to improve the quality and capabilities of this interface. Research projects on adaptive-arrays, airborne surveillance radar antennas, and multibeam antennas are described here.

The need to detect smaller targets at longer ranges in intense electronic counter-measures (ECM) environments has sharply increased the performance requirements imposed on future airborne early warning (AEW) radar systems. Similarly, increasing demands on the aerodynamic performance of the aircraft that carry the radar have reduced the available payload. Consequently, the radar designer is faced with the problem of providing significant increases in detection performance with simultaneous reductions in the weight of the radar. Two principal factors determine the ability of the AEW radar to satisfy the future requirements of the Navy: the weight-effectiveness factor and the antenna pattern control. The weight-effectiveness factor K is defined by

$$R^4/\sigma = KW^2, \quad (1)$$

where R is the detection range, σ is the target size, and W is the radar weight. That is, K is a factor relating the detection performance, measured by the range to which a given target can be detected, to the total radar weight. It is helpful to define K as the product of two component weight-effectiveness factors—one (K_a) associated with the radiating characteristics of the antenna, and another (K_p) associated with the remainder of the radar components.

An order of magnitude improvement in K_p can be achieved by the use of a solid state transmitter incorporating high-power bipolar transistors. This has been confirmed by the construction and demonstration of the critical components in the system. A similar order-of-magnitude improvement is being sought in K_a by use of a radical approach to the antenna design architecture and by the use of new materials. This is being investigated in scale-model experiments such as the one illustrated in Figure 11, which shows a model of a VSTOL candidate aircraft with an advanced-design radar antenna being tested on the antenna range.

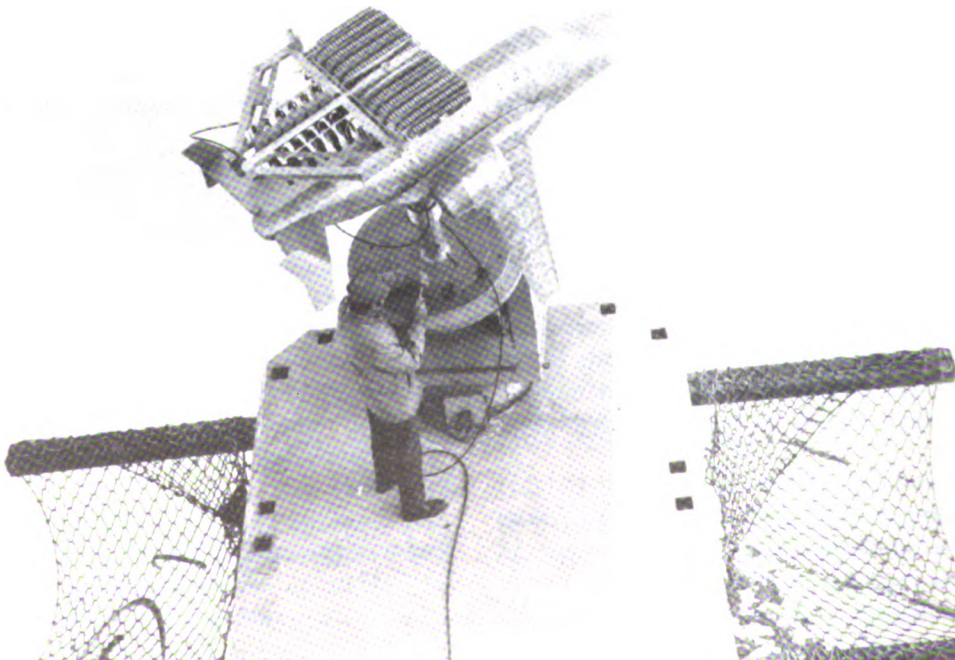


Figure 11. Scale model of a candidate AEW aircraft with test radar antenna on the NRL antenna range

At the same time, ways are being explored to provide the degree of pattern control necessary to reject sidelobe and mainlobe jamming and clutter. Null steering, the generation of accurate sum and difference patterns, and the maintenance of low sidelobes are new techniques recently developed and patented for accomplishing these functions simultaneously.

Adaptive antenna systems are being investigated for achieving effective suppression of RF interference. These systems generally consist of an array antenna and a real-time adaptive receiver-processor which, given a beam steering command, samples its environment by taking a radar "snapshot," and then automatically proceeds to adjust itself toward optimization of the signal-to-interference ratio. The theory associated with these systems has progressed rapidly in recent years, but experimental performance/evaluation has lagged considerably. NRL has taken a significant step toward improving this imbalance by the design

and implementation of an adaptive array digital processor facility. A block diagram of the instrumentation is shown in Figure 12.

Two principal modes of operation are available for handling the coherent, digital, snapshot data. The first utilizes a 70-MHz reference oscillator to get synchronous intermediate frequency (IF) detection, and simply records the in-phase and quadrature (90° out-of-phase) snapshots at maximum rate on magnetic tape for later off-line processing. The second mode utilizes the IF beamformer output as feedback to get IF correlator detection of error signals that can then be used for computer control of the IF weights of the beamformer. The IF weights may be frozen at any time to obtain a resultant adapted antenna pattern. Initial calibration/validation experiments are being run with a linear array, and development of the required software is nearly complete.

The objective of exploring new multibeam concepts and techniques for microwave antennas is being pursued under a basic research program. Various types of lenses and transmission line networks can be used with a radiating array or aperture to form simultaneous directional patterns. For applications that require such patterns, it is highly preferable to use a multibeam system rather than a separate antenna for each pattern: potential savings in cost, weight, and size are apparent. Furthermore, to enhance the weight-effectiveness factor, it is desirable to minimize the size of the multibeam lenses and networks. To this end, symmetric antenna feed networks for complex multielement arrays have been devised that can be cut in two on their plane of symmetry, thus reducing the number of network components by one-half. Three-dimensional lenses have also been generated that can replace much larger two-dimensional lenses in linear antenna-array applications.

In summary, the current radar antenna research programs at NRL involve both theoretical and experimental effort, range in scope from basic research to advanced development, and are relevant not only to radar systems, but to several other technology areas as well.

[Sponsored by NAVSEASYS COM, NAV-AIRSYS COM, and ONR]

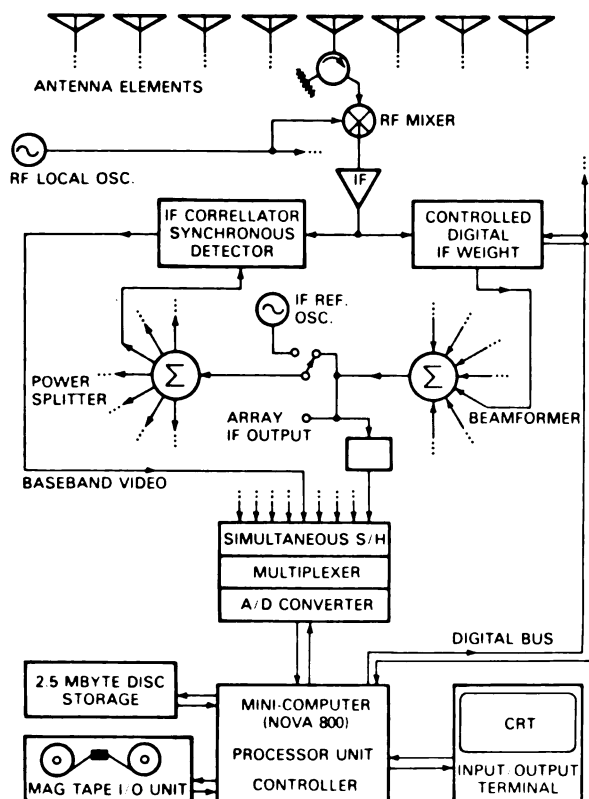


Figure 12. NRL general-purpose adaptive-array digital processor for suppression of RF interference

Blue-Green Laser Sources, by R. Burnham, *Optical Sciences Division*

Lasers operating in the blue and green spectral regions are of fundamental interest to the Navy for applications involving the propagation of light through seawater. Examples of proposed underwater applications of lasers include remote sensing of submerged objects, underwater ranging (LIDAR), communication with submerged platforms, bathymetry, and ocean bottom profiling. Most of these applications require pulsed laser output (for range gating) and/or high power for penetration to significant depths. In addition, the lasers must convert electrical power into coherent radiation in the blue-green spectral region with an efficiency of at least 1%. This efficiency requirement arises because of the limited prime electrical power available on the ships or aircraft that will carry the lasers. Recent experimental work at NRL has led to the development of new blue-green laser sources which appear to be ideally suited to a number of undersea applications.

The most fundamental requirement for underwater applications is, of course, for a laser at the proper wavelength. However, depending on the application, lasers operating within a rather broad wavelength range may be suitable. Figure 13 shows the attenuation coefficient (which includes contributions from both absorption and scattering) for several types of ocean water in the wavelength region of interest for underwater applications. It may be seen that, for the clearest deep ocean water (Type I), a laser operating between 450 and 500 nm is most desirable for maximum depth penetration (minimum absorption). For propagation through ocean water typical of shallower depths (Type III), the wavelength of the laser is less critical but communication over long distances (≥ 100 m) may not be possible because of the rather large attenuation coefficients.

During the last year, new laser sources with great promise for underwater applications have emerged as a result of NRL research. These new laser sources result from the conversion in wavelength of the output of the efficient XeCl excimer laser. This laser ordinarily operates in the UV region at 308 nm. However, by using the mechanism of stimulated electronic Raman scattering in atomic

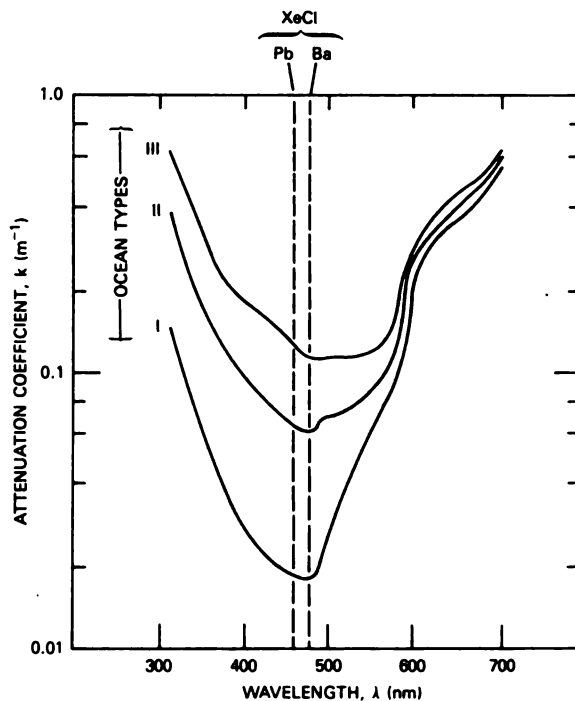


Figure 13. Optical attenuation curves for ocean water. The wavelengths of the XeCl laser, frequency shifted in lead and barium vapors, are shown by the dashed lines.

vapors, the output from the XeCl laser has been converted to several different wavelengths in the blue-green region. The most efficient conversion has been observed in atomic vapors of lead and barium. In lead vapor, the wavelength of the XeCl laser has been converted to 459 nm with an overall energy efficiency of about 50%, and in barium vapor, the output has been converted to 475 nm with an efficiency of 25%. The wavelengths of the converted XeCl lasers are indicated by the dashed lines in Figure 13.

The pump laser and Raman conversion cell are shown in Figure 14. Conversion of the laser output wavelength takes place during the propagation of the focused XeCl laser beam through the metal vapor in a simple heat-pipe oven. The output, shifted to 475 nm in barium vapor, retains the temporal pulse shape and frequency distribution of the UV pump laser. The bandwidth, output wavelength, and optical pulse length from the pump laser are sufficiently adjustable that the output of the Raman lasers can be tailored to suit particular underwater applications. As examples, applications involving distance ranging require short

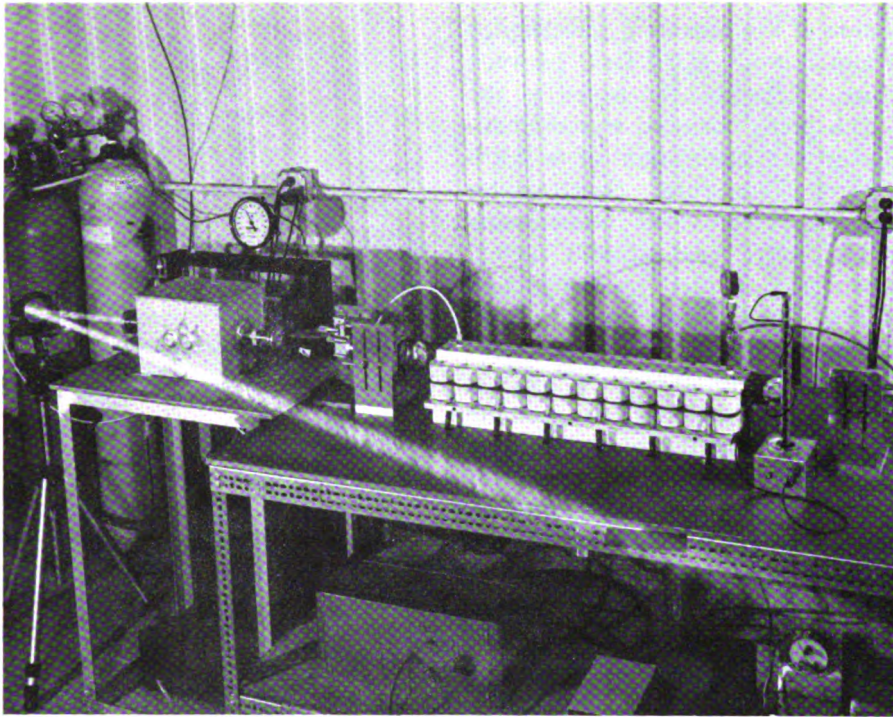


Figure 14. A discharge-pumped XeCl laser (right) and heat-pipe oven (left) being used in Raman conversion experiments. The visible beam emerging from the heat-pipe results from conversion of the XeCl laser wavelength from 308 to 475 nm in barium vapor.

pulses, those involving communication may require a narrow spectral bandwidth.

In its present stage of development, the XeCl laser has an electrical efficiency of several percent. This efficiency, when multiplied by the efficiencies for wavelength conversion given above, gives an overall blue-green laser efficiency very near 1%. Research is being directed toward improving the efficiencies of both the pump laser and the Raman converters. Experiments are also being carried out to demonstrate these laser sources with pulse energies of 1 J and average optical powers of 100 W.

[Sponsored by NAVELECSYSCOM]

High-Resolution, Long-Path, Atmospheric Transmission Measurements, by J. A. Dowling, S. T. Hanley, and R. F. Horton, *Optical Sciences Division*

The Navy is concerned with the ability of many types of electro-optical (E-O) devices to operate over long atmospheric paths. Analyses of the effectiveness of these devices and of sys-

tems utilizing them require accurate and reliable information about atmospheric properties in the two principal infrared (IR) "window" regions where many of these systems operate: that is, from 3 to 5 μm and 8 to 12 μm . Detailed information is needed about the variations of IR atmospheric transmission with wavelength, meteorological conditions, and propagation path length so that atmospheric effects can be accurately assessed. The objective is a computational model or predictive formula that can determine the transmission at any given wavelength for any combination of atmospheric conditions. NRL research during the past several years has delineated the usefulness and limitations of existing atmospheric transmission models, and has provided information needed for improvements in these analytical tools.

Long-path transmission experiments have been performed at NRL using a variety of infrared and visible sources and large transmitter and receiver optical systems contained in several large trailers deployed at a variety of field locations. The primary

emphasis has been on measurement of atmospheric attenuation at the operating wavelengths of the deuterium fluoride (DF) laser between 3.6 and 4.1 μm . Recently, the scope of the transmission data being acquired was dramatically enlarged by the acquisition of a high-resolution Fourier Transform Spectrometer (FTS) system which provides transmission spectra over the entire near-infrared region. Moreover, when FTS is used in conjunction with atmospheric laser extinction measurements, it provides spectral resolution sufficient to show all atmospheric absorption details. This combination also provides an absolute transmission calibration for the high-resolution spectra—it is a unique feature of the NRL studies and represents a state-of-the-art achievement. The long atmospheric paths afforded in the NRL field experiments provide a range of important parameters (*e.g.*, water vapor content) not attainable in laboratory experiments, and the system provides detailed data that enable the modeler to make a critical comparison of his predictions with real-world observations.

The infrared mobile optical radiation laboratory (IMORL) has recently been used for measurements over a 5-km path at Cape Canaveral Air Force Station (CCAFS), Florida and a 6.4-km path at the White Sands Missile Range (WSMR), New Mexico. Figure 15 shows measured molecular absorption coefficients (in km^{-1}) vs water vapor partial pressure for 2 DF laser lines. The data are from 1975 experiments at the CCAFS site and a coastal site in southern California, and the WSMR site in August 1978. Also shown are calculated curves for each case (dashed lines) and curves fitted to the CCAFS experimental data (solid lines).

The data for the P_1 -8 line taken recently at WSMR show good agreement with the 1975 measurements and model comparisons shown in Figure 15(b). For the P_2 -5 DF laser line in Figure 15(a), the agreement is not as good. This line is located toward the short wavelength extreme of the DF laser operating region and is substantially influenced by a molecular water vapor continuum absorption present throughout the DF laser region. This continuum absorption is to be distinguished from line absorption due to many individual molecular vibration-

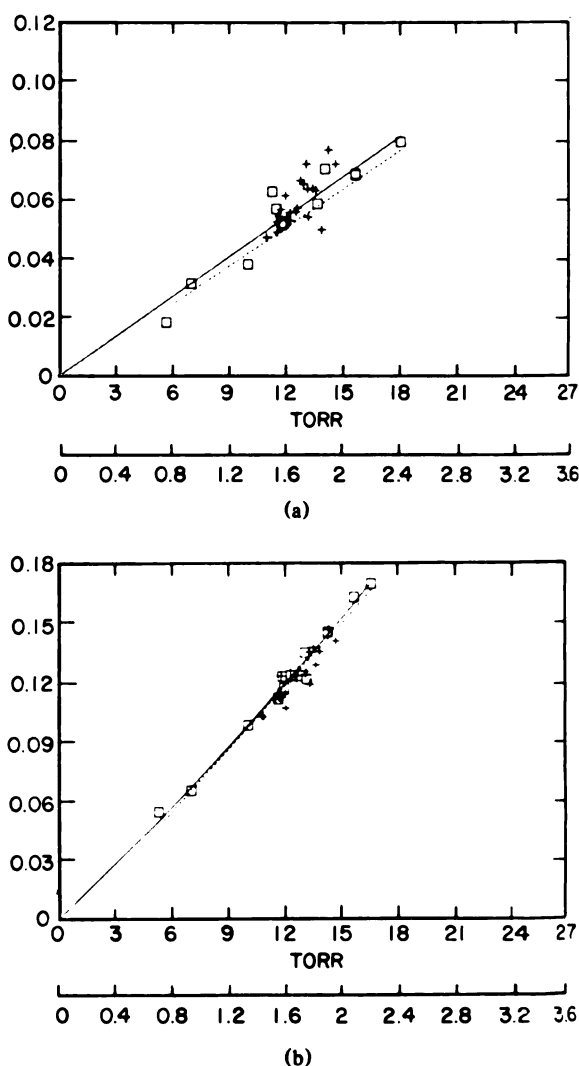


Figure 15. Molecular absorption coefficient (km^{-1}) vs partial pressure of water vapor over a 5.1-km path at CCAFS, March 1975 ($\square$); over a 5.6-km path in southern California, August 1975 (+); and over a 6.4-km path at WSMR, August 1978 ($\circ$). Dashed lines shown calculations based on a computer model, and solid lines show fits to the CCAFS data. Data are for the DF laser lines P_2 -5 at 2703.399 cm^{-1} (Figure 15(a)) and P_1 -8 at 2717.538 cm^{-1} (Figure 15(b)).

rotation absorption lines throughout this spectral region. Although it is weak, this continuum absorption is nevertheless important, and can be the dominant limitation on long-path transmission, as in this case. Figure 16 shows a portion of a high-resolution, long-path transmission spectrum recently obtained with the FTS system. The spectrum was calibrated

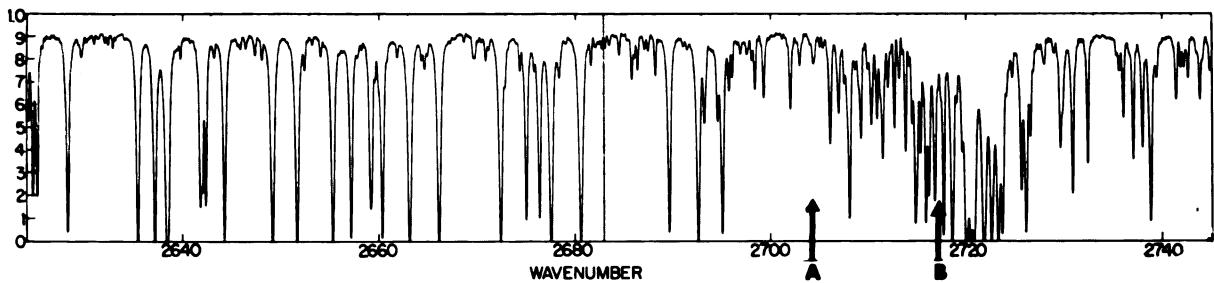


Figure 16. Portion of an absolute transmission spectrum of a 6.4-km path recorded in August 1978, at WSMR, New Mexico (elevation 1440 m). Atmospheric conditions were 11.7 kPa (8.8 Torr) partial pressure of water vapor, 33.3°C air temperature, 880 kPa (660 Torr) total pressure, and 105 km visibility. A and B show the locations of the DF laser lines whose absorption data are shown in Figure 15.

in absolute transmission by means of the extinction data in Figure 15 for the two DF laser lines whose positions are indicated by the letters A and B. The spectral width of the laser emission lines ($\sim 10^{-4} \text{ cm}^{-1}$) is much less than the width of atmospheric absorption lines shown in the spectrum ($\sim 0.3 \text{ cm}^{-1}$).

The maximum transmission along the 6.4-km path is only about 90%, primarily because of water vapor continuum absorption. An additional attenuation due to scattering by atmospheric aerosols normally contributes to transmission loss in field experiments. However, the very high visibility conditions (negligible transmission loss for visible wavelengths) in the desert at WSMR indicate that aerosol scattering losses can be neglected.

By closely examining the details of the spectrum in Figure 16, subtle differences in atmospheric effects can be studied and should help to explain why the Figure 15(a) data for the WSMR desert (1440 m elev.) are different from the sea level CCAFS data. One obvious candidate is the 13% lower atmospheric pressure at WSMR which will alter the atmospheric absorption line structure and the water vapor continuum absorption.

Detailed analyses of these spectra are planned along with more long-path measurements at WSMR and other sites to further improve our understanding of atmospheric effects on infrared transmission. The information already obtained in these experiments has greatly increased confidence in modeling the propagation of infrared laser wavelengths in the atmosphere.

[Sponsored by NAVSEASYS COM]

First Optical Transfer Function Measurements in the Sea, by V. A. Del Grosso, *Ocean Technology Division*

Scattering of light in the ocean is of basic interest to the Navy because it degrades the performance of underwater imaging and other optical systems. Light scattering affects the following three parameters: (a) the range of penetration of artificial illumination, (b) the fidelity of transmission of optical imagery, and (c) the degree of degradation of the phase relationship or coherence between two points in the optical wave field. The first of these parameters is described by the beam attenuation coefficient α , which includes the scattering loss. The second parameter is best characterized by the Optical Transfer Function (OTF) whose magnitude is the Modulation Transfer Function (MTF), which is a measure of image contrast degradation. The phase of the OTF is the useful Phase Transfer Function (PTF), which characterizes image shift. The third parameter is exemplified by the Mutual Coherence Function (MCF), which gives phase relationships in the optical field. This last measurement can be specified either along a wavefront (transverse or spatial) or along a ray (longitudinal or temporal). Spatial coherence is important to both holographic and synthetic aperture underwater imaging systems. Temporal coherence is a requisite for underwater heterodyne communication and doppler velocimeter systems.

The fundamental cause of subsurface light scattering is perturbations in the apparent refractive index of the medium. These perturbations are ultimately due to fluctuations in

physical parameters and composition of seawater such as temperature, pressure, salinity, and, in a broad sense, particles of a size comparable to the wavelength of light. Macroscopic variations are the result of currents, internal waves, turbulence, and other mechanical stirring and diffusive mixing processes that affect waters of diverse origin and history. These fluctuations continue to affect α , OTF, and MCF for appreciable periods after their genesis. This is because the diffusive mixing is much slower than the momentum which perturbed the medium.

Narrow angle, forward light scatter is of paramount interest. It is caused by particles large with respect to the wavelength of light and by turbidities, which are patches of water characterized by a relatively uniform refractive index fluctuation that differs slightly from the surrounding medium.

Laboratory validations of new instruments and theory (NRL's 1975 Review, p. 123) were followed by development of light scattering equipment (Figures 17 and 18) capable of yielding the complete OTF to depths of over 5000 m. The wet-end portion includes a laser

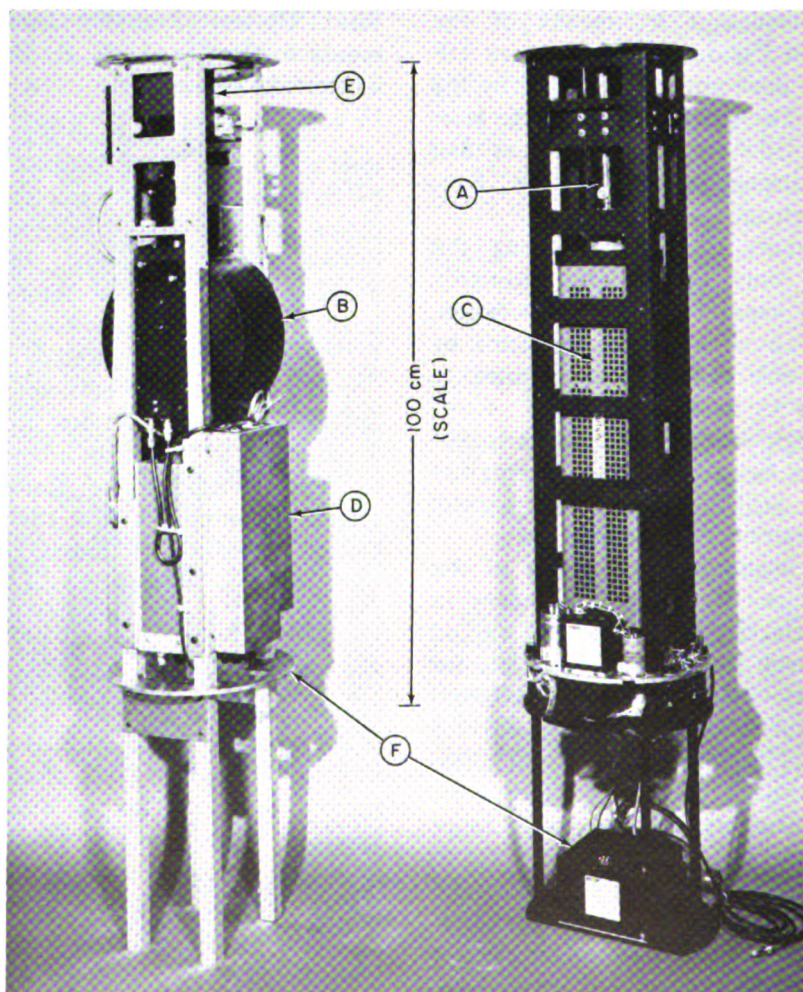


Figure 17. The Optical Transfer Function system (without pressure housings). The projector-illuminator on the right contains an He-Cd laser illuminator (C) with a 5-cm beam expander-collimator (A). The analyser on the left has a colocated bar pattern-drum analyzer-encoder wheel (housing a photomultiplier) (B) along with a microprocessor (D) and remote focusing decollimator (E). The lower end of each unit contains internal power supplies (F).

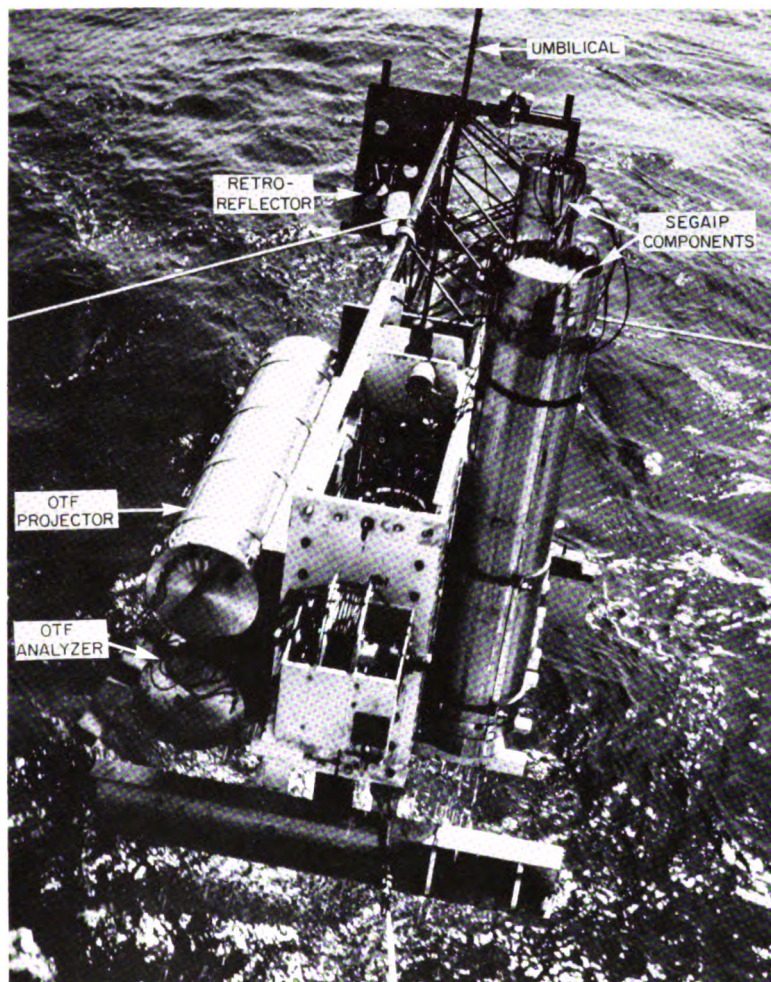
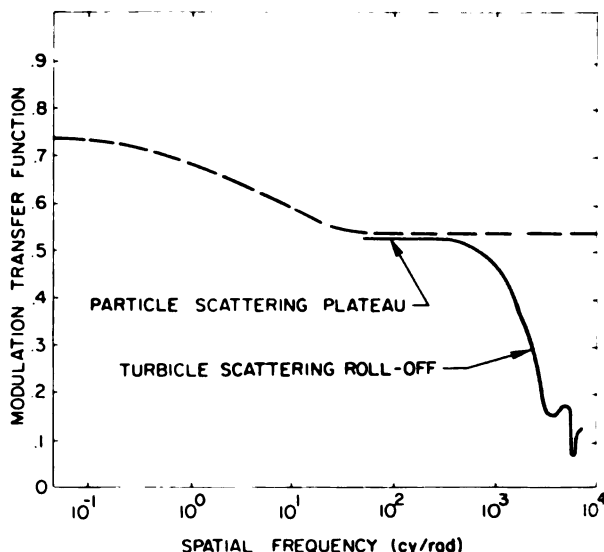


Figure 18. The test vehicle or *FISH* on which the Optical Transfer Function system was deployed. The two horizontal housings on the left contain the projector-illuminator and analyzer of Figure 17, respectively. The tubular structure to the rear carries a 3-mirror retroreflector that provides a nominal 7-m optical water path. A single umbilical (dark line at top) provides support, power, and telemetry. The white ropes (to sides and bottom) are aids for launch and retrieval. The vertical housings to the right comprise NRL's range-gated wide-angle laser-illuminated photographic system named *SEGAIP*. Hidden from view is a 12-bottle *Rosette* water sampler.

projector and OTF analyzer. The topside equipment includes a microprocessor-controlled interrogator and visual display with paper print-out of data. The system was deployed in the Sargasso Sea above the Hatteras Abyssal Plain some 500 nmi east of South Carolina aboard USNS HAYES in May 1978. It yielded the first *in situ* OTF data to a depth of 940 m. Concurrent water samples were taken for analyses of particle size and number density in the 1 to 100- μ m size range.

Pertinent theory predicts that the effect of particles on MTF is a plateau in spatial frequency, while the effect of turbidities on MTF is a superimposed roll-off (for which the logarithm of MTF varies as the inverse square of spatial frequency). Figure 19 is a plot of one of the MTF curves measured in May 1978 compared to that calculated by Mie theory from the particle analyses alone. Over the limited range of spatial frequency utilized in this ocean test, good agreement was found at the particle

Figure 19. Modulation Transfer Function as calculated from the particle analyses (dashed line) and as measured directly *in situ* at a depth of 560 m (solid line). The abscissa (spatial frequency) is the Fourier transform-coordinate that is conjugate to angular measure in ordinary space (vice transform space).



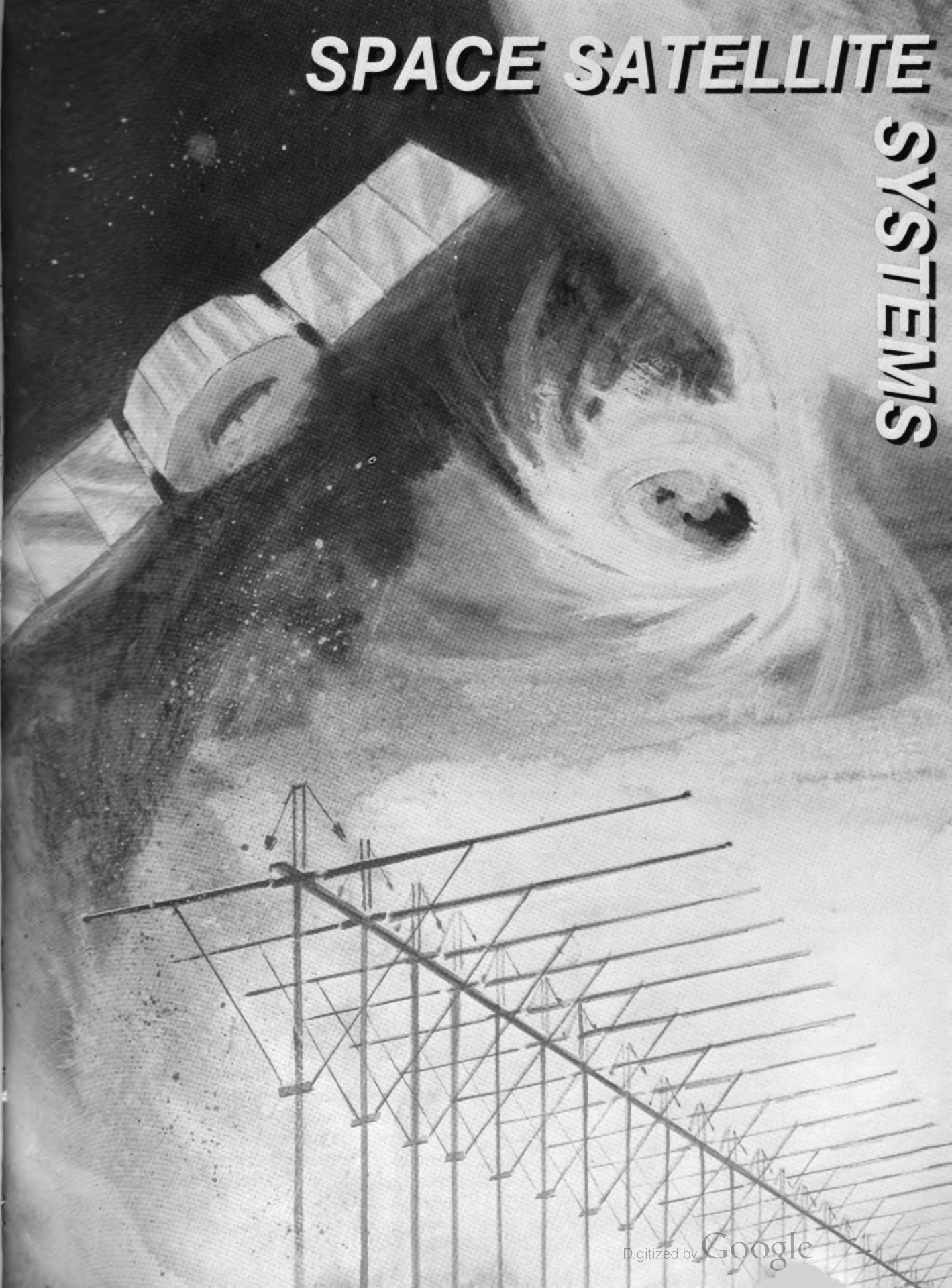
scattering plateau. The observed roll-off of MTF beyond this plateau is consistent with the existence of turbidities of 1 cm size and 0.1°C rms temperature fluctuation. PTF data (not shown) displayed phase shifts in agreement with the behavior expected for probabilistic turbulence scattering (deterministic particle scattering has a zero PTF). Turbidities are expected to cause MCF degradation as well as MTF roll-off.

These are the first data which exemplify *in situ* OTF and predict the behavior of deep ocean MCF (through the determination of turbidities). It also yields, through proven theory for the first time, the basic optical propagation parameters of scattering loss and attenuation (the logarithm of the MTF at the particle scattering plateau is α). This information is

crucial to the optimum use of artificial light in the ocean. The demonstrated MTF roll-off severely limits noncoherent optical resolution in water. The implied degradation of MCF severely restricts coherent underwater applications such as holographic and synthetic aperture imaging and proposed optical communication and doppler velocimeter heterodyne systems. A lower spatial frequency capability in future equipment will permit delineation of the lower particle scattering plateau which is expected to yield the diffuse attenuation coefficient γ . Extension of these OTF measurements to more locales, seasons, and depths is required to gain a good working knowledge of optical oceanography.

[Sponsored by CND and ONR]

SPACE SATELLITE SYSTEMS



SPACE SATELLITE SYSTEMS

Twenty-one years ago, the only Earth satellite was the Moon and the only means of studying the stars without atmospheric interference or examining our home planet from a distance were brief flights of high-altitude aircraft, sounding rockets, and balloons. Today, more than 4400 objects are orbiting the Earth and are providing important new capabilities in communications, navigation, surveillance, and scientific data collection. NRL has been a significant contributor to the development of these capabilities and maintains a continuing dedication to their improvement through research.

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Navy Space Applications and Policy, by L. J. Abella and H. W. Gandy, *Space Systems Division*

Space technology has advanced from Sputnik I in 1957 to the point where space systems significantly affect Navy missions. Over-the-horizon detection, classification and targeting, surveillance of shipping lanes and critical ocean areas (gaps), navigation, collection of operational environmental information, and command, control, and communications are examples of present and potential space-system applications which greatly concern the Navy.

In view of its increasing use of space systems, the Navy recognized a need for a space policy. As part of the effort to develop this policy, NRL collaborated with other Navy activities and private institutions in a Navy Space Study (NSS) in support of the Chief of Naval Operations (CNO OP-96). The study objectives were to identify the space systems that support the Navy's operational requirements now, to identify those programmed and conceptual systems that could provide additional support in the future, to measure the Navy's dependence on each of these systems, to review system vulnerabilities, and to develop program recommendations. The findings of the NSS include the following:

- Virtually all submarines and surface ships have satellite terminals, and installations on numerous aircraft are planned.
- Reports from Navy users indicate that satellite systems are critical to support naval operations.
- More regard must be given to electromagnetic and physical threats to space systems.

The NSS found that the Navy is using satellites for many applications and that space systems are providing increasingly important support for the Fleet. The importance to the Fleet of satellite communications is being demonstrated through the use of the GAFILLER/MARISAT UHF system and the SHF Defense Satellite Communication System II (DSCS II). Other space systems and terminal designs are in development or in conceptual planning to provide continuing and improving satellite communication service for the Fleet. Beginning in 1964 the current Navy navigation satellite, TRANSIT, has provided precise posi-

tion information for submarines and surface ships. The future NAVSTAR Global Positioning System (GPS) will provide global 24-hour, all-weather navigation to submarines, ships, aircraft, ground troops, and other users. This DoD system, based on NRL technology developed in the TIMATION and NTS satellite series, is scheduled for completion in the early 1980s.

Satellite surveillance is a relatively new concept for the Navy but one of growing importance as a force multiplier. Surveillance of space objects, on the other hand, is an area in which the Navy has been involved since 1960 with the Naval Space Surveillance (NAVSPASUR) System. The modernization program for NAVSPASUR is described in the following article. The importance of satellite weather information to the Fleet was demonstrated during the conflict in Southeast Asia. Today, the Defense Meteorological Satellite Program (DMSP) provides environmental data to several aircraft carriers, and by 1981 DMSP terminals will be on board all major carriers. In addition, non-DoD satellites, such as ITOS, TIROS, and SEASAT, also provide environmental data for selective use by the Navy.

NRL, with its expertise in space systems, space technology, and materials and device technology, provides support to all aspects of Navy space activities. The findings of the NSS were one of the inputs that provided the basis for the Navy Space Policy, signed and promulgated by the Chief of Naval Operations in June 1978. This policy states, in part, that the Navy will:

- plan for optimum use of space technology and assets in support of Navy roles and missions;
- procure and manage those systems which purely, or primarily, fulfill Navy missions and requirements;
- ensure that adequate capabilities and procedures exist to defend its space systems against attack and interference; and
- participate appropriately in those programs assigned to other services or agencies that may further the Navy's capabilities to accomplish its mission.

Specific program recommendations to implement this policy also were made in the

NSS and are being reviewed by the office of the Chief of Naval Operations for planning and programming of Navy space activities.

[Sponsored by CNO-OP-96]

Space Surveillance Modernization, by R. R. Zirm, *Space Systems Division*

The Naval Space Surveillance System was developed at NRL from 1958 to 1964 for the detection of nonradiating space objects passing over the continental United States. The system has been operational since 1960. It is basically a multistatic continuous-wave radar, consisting of six receiving stations and three interspersed transmitting stations, all on a great circle from Fort Stewart, Ga., to San Diego, Calif. Large linear antenna arrays at the transmitting stations form fan-shaped beams in the plane of the great circle. The receiving stations use multiple-array interferometers to measure the time and angle of arrival of signals returned from objects traversing the fan beam. A space object is thus detected, and its positions are determined for computation of its orbit. Satellite positions and orbits are calculated at system headquarters in Dahlgren, Va. Objects are routinely detected at altitudes from 139 km (75 nmi) to about 14 000 km (7500 nmi). The operational detection capability at 14 000 km ranges from 80° to 120° west longitude. Large objects have been detected at altitudes over 18 000 km (10 000 nmi).

Since this system was designed and installed, many of the subsystems and components of the receiving station equipment have become obsolete. Many of the vacuum tubes are no longer produced, and the transmitter electronics are becoming obsolete. Parts replacement and degradation is becoming a significant problem, although there is no immediate danger of catastrophic system failure. In 1978 the NRL modernization program began to upgrade the system in order to ensure its continuing usefulness. The receiving electronics were redesigned to use modern, readily available components to ease the obsolescence problem and provide improved performance.

From 1979 to 1983 the receiving station subsystems will be replaced. Concurrent and subsequent modernization of the transmitting

sites is under consideration. The existing receiving-station electronics use analog components almost exclusively. The received information is digitized just prior to transmission to system headquarters. In the new design, modern digital technology is being used extensively. The decision to use digital methods was influenced by several factors: system sensitivity, cost, phase stability, development time, and field maintenance.

Digital components that are off-the-shelf and programmable can be used to reduce the predetection bandwidth by as much as a factor of 50 compared to the present design. The resulting improvement in sensitivity will allow the system to routinely detect and track satellites at orbital altitudes exceeding 18 000 km. In contrast, achieving the same improvement by using analog methods would have required an enormous number of special narrow-band filters. Currently 580 such filters span the entire doppler spectrum; 9600 would have been required to obtain the improved sensitivity. Furthermore, the processing capability and greater operating range inherent in the digital design will permit detection and tracking of several targets simultaneously.

With the narrow-bandwidth requirements of the modernized system, another consideration is the effects of aging and environmental conditions. These factors would cause bandwidth changes and attendant phase-slope changes in analog filter networks, whereas digital equipment is nearly independent of these influences under normal operating conditions. The fault-tolerant digital design of the new equipment also has a self-diagnostic capability; software will locate a faulty component at the module level. This automatic feature will maximize performance while reducing the skills required of remote-station operating personnel to those of caretakers.

[Sponsored by CNO, PME-106-4]

Satellite Observations of the Ionosphere, by J. M. Goodman, *Communications Sciences Division*, and R. L. Beard and R. R. Zirm, *Space Systems Division*

The DoD Global Positioning System (GPS) will make precision navigation and timing available to Navy users, among others.

When fully deployed in the 1980s, GPS will provide worldwide near-instantaneous service at all times. Since the system is based on the measurements of time-of-arrival of signals transmitted from satellites, and the grade of service is so high, the effects of the ionosphere on signal propagation can be a significant limitation on performance. Specifically, inhomogeneities in the electron population of the ionosphere produce disturbances in the phase surfaces of radio waves, and these disturbances introduce amplitude and phase scintillations in the received signals as well as uncorrectable path delay errors. During severe magnetic storms, system outages may occur.

The Navy NTS-2 satellite, developed at NRL as a test bed for GPS, provided coherent transmissions at 335 and 1580 MHz, and these are being used to study ionospheric parameters. The primary objective of this research is to quantify the limitations which the ionosphere will pose for Navy users of the GPS. A second objective is to derive information about the ionosphere itself which may yield long-term benefits to other Navy systems.

During 1978, NRL scientists derived information of potential utility from data that had been obtained from NTS-2 between October 5 and December 6, 1977. During that interval, more than 126 passes of the satellite were observed at the Panama receiving station (8.95°N, 80.58°W). This site was ideal for studying propagation through the equatorial regions of the ionosphere. The geometry was especially favorable for studying the northern portion of the zone of high electron content called the equatorial anomaly and for investigating the morphology of the scintillation zone which surrounds the magnetic equator. In fact, during a single observation period, the portion of the anomaly in the Northern Hemisphere could be observed twice: on the north-to-south and the south-to-north transits of the satellite.

Figure 1 is a montage of NTS-2 ranging data between November 28 and December 5, 1977. The figure shows the equatorial anomaly in total electron content in terms of the difference between the group path delay measurements at 1580 MHz and 335 MHz respectively. Both frequencies are similarly affected by factors which are unrelated to the ionosphere, but the lower frequency is substantially more affected by the ionosphere than the higher one. Hence the separation of the two curves reflects the differential time delay introduced by the electron content along the ray path. The northern boundary of the equatorial anomaly (corresponding to the peak ionization level as indicated by arrows in Figure 1) moves farthest poleward (to the left) on December 2. This is associated with a large increase of the total electron content (large separation of curves) at the closest point of approach (CPA) of the satellite and correlates with an increase in geomagnetic activity observed during that period by a satellite magnetometer. Strong amplitude scintillation is typically observed toward the equator from the anomaly boundary, but this is not seen explicitly in the phase records depicted in Figure 1.

Observations have also been made from a site near Washington, D.C., where only north-to-south portions of the NTS-2 orbit are visible. Figure 2 shows another geomorphologic feature of the ionosphere observed December 2, 1977. This feature is termed the midlatitude trough and represents a region of the ionosphere with reduced electron population. The effect of the trough is shown by the top curve in Figure 2;

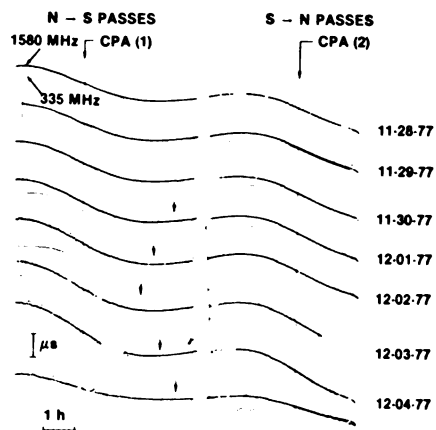


Figure 1. Curves from which the differential group path delay corresponding to NTS-2 transmissions at 1580 and 335 MHz were obtained. At the Panama observation site, each complete pass consisted of north-to-south and south-to-north components. The two closest points of approach (CPA) of the satellite were roughly 7 hours apart. Arrows indicate the northern boundary of the equatorial anomaly, which is where the electron content is highest.

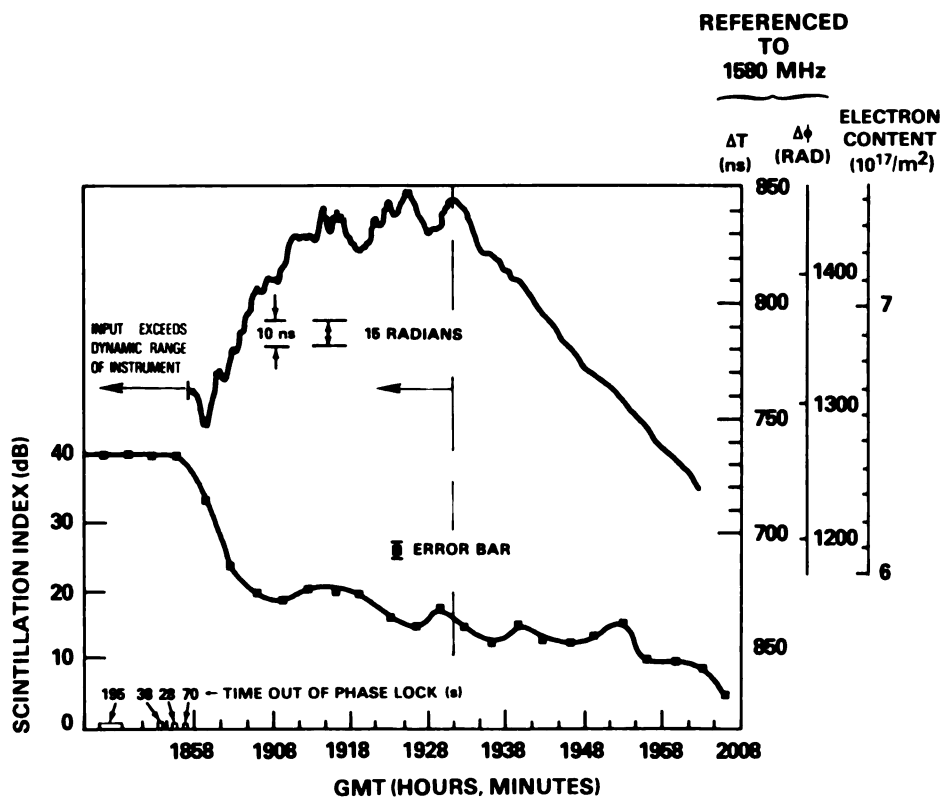


Figure 2. Differential phase (top curve) and amplitude scintillation data (bottom curve) for December 2, 1977, observed at Washington, D.C. Three scales are shown for the top curve: differential group path delay (ΔT), differential phase ($\Delta \phi$), and total electron content in the slant path.

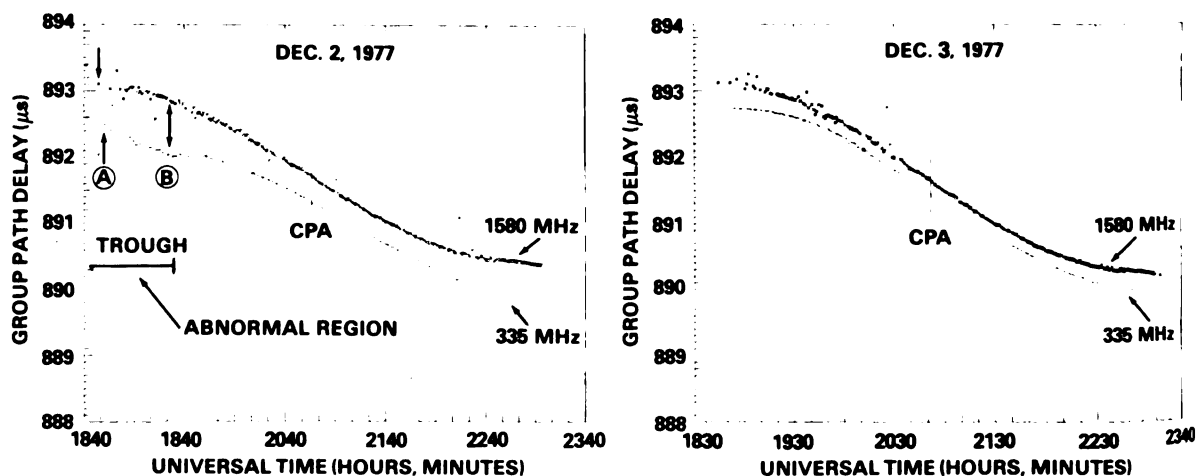


Figure 3. Group path delay as observed at Washington, D.C. The midlatitude trough is evident in the December 2 data (left plot). In the absence of the trough, the separation between curves would be greater at A than at B due to the greater path length through the ionosphere. The trough had contracted northward on December 3 and is not evident in the data (right plot).

the total electron content, instead of continuing to rise smoothly from right to left (as slant range increases), levels off and actually diminishes. The effect on scintillation index, while significant, is evident in a more restricted region. The midlatitude trough is closely associated with the expansion of circumpolar features following magnetic storms, and its expansion correlates with observations of increased average levels of amplitude and phase scintillation at midlatitudes.

The left plot in Figure 3 shows the more precise phase record obtained on December 2 and the strong amplitude scintillation observed within the trough. Fading in excess of 40 dB was noted, and the receiving system was inoperable (out of phase lock) for a substantial period of time. The trough would not normally be observed at Washington, D.C. during magnetically quiet periods; in the right plot in Figure 3, included for this comparison, the trough is not evident.

These experiments have provided GPS managers and system engineers with statistical information which can be used in developing operational guidance for current systems and design criteria for future ones. The experiments have shown that two ionospheric features, the equatorial anomaly and the midlatitude trough, are not just of interest to geophysicists but can have profound effects on system operations. These two features appear to expand toward one another during periods of increased magnetic activity which follow solar flares, and this may provide an argument for doing ionospheric forecasting, specifically the forecasting of magnetic storm effects on the basis of solar flux measurements.

[Sponsored by NAVELECSYSCOM]

Solar-Cycle Observations from SOLRAD 10, by R. W. Kreplin, *Space Science Division*

Since 1964 the NRL SOLRAD program has provided a nearly continuous record of the Sun's x-ray emission. It has now covered more than one solar cycle, from solar minimum (1964-1965) through maximum in 1969 and through minimum in 1975-1976. The ascending part of the new cycle, number 21, was monitored by SOLRAD 10, until it ceased providing useful data in June 1978. Striking increases in

x-ray emission were observed in the first 6 months of 1978. Subsequent data have been received from SOLRAD II but are not fully analyzed.

Since x-ray emission below 1 nm is absorbed in the lower D-regions of the ionosphere and thereby determines the lowest operating frequency for any daylight communication path, knowledge of the instantaneous value of x-ray flux can be used in communication management. Recently SOLRAD data have been used in management of Navy HF communications in the Eastern Pacific with significant improvement in reliability. But knowledge of long-term variability is also important as a design parameter in these and other military systems whose performances depend on ionospheric conditions.

Data from satellite passes over the NRL Blossom Point telemetry station have been averaged for each day, excluding exceptionally high values coincident with solar flares, and plotted to describe the long-term variability of the solar x-ray emission. The measurements were made in the satellites by x-ray photometers of a standardized design developed and updated at NRL during the past 20 years. They are simple gas-filled diodes whose wavelength response is determined by the window and the gas filling. The 0.1- to 0.8-nm photometer has a beryllium window and argon filling, and the 0.8- to 1.6-nm detector has an aluminum foil window and is filled with nitrogen. Since there is no gas amplification, very small currents of the order of 10^{-12} A must be amplified by sensitive and stable electrometer amplifiers. These amplifiers and photometers have operated in orbit without change in sensitivity for periods longer than 7 years.

The measurements during 1978 were examined in relation to the behavior of x-ray emission late in solar cycle 20 and in the solar minimum. Late in cycle 20 the emission was quite variable. In mid-1974 the daily-average flux detected by the 0.1- to 0.8-nm detector varied between 10^{-3} and 10^{-4} mW/m² (erg/cm²·s). Later in the year the levels dropped below the detection threshold of 10^{-5} mW/m², and the 0.8- to 1.6-nm flux also decreased but with smaller fluctuations. In 1975 the levels were quite low, dropping below threshold levels up to a month at a time.

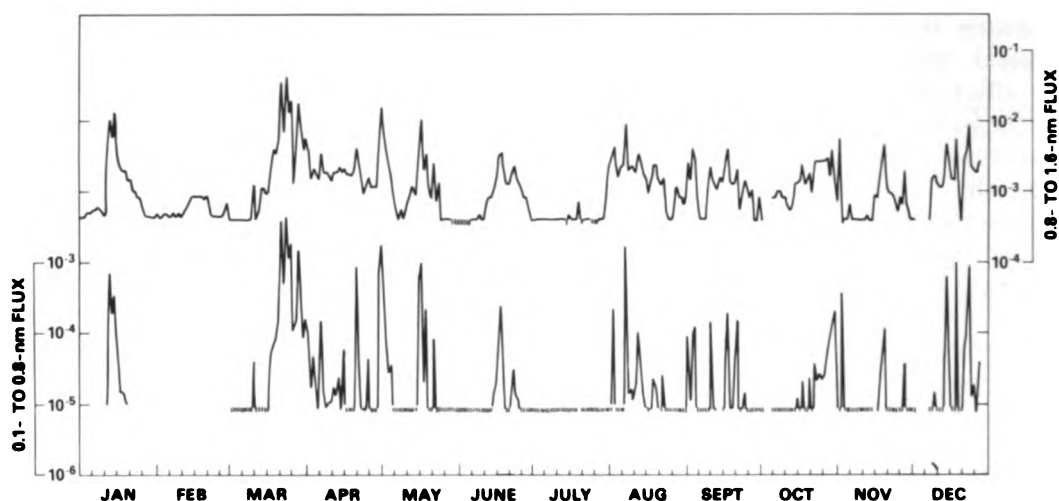


Figure 4. SOLRAD data for 1976. The units of flux in each of the two wavelength bands are milliwatts per square meter.

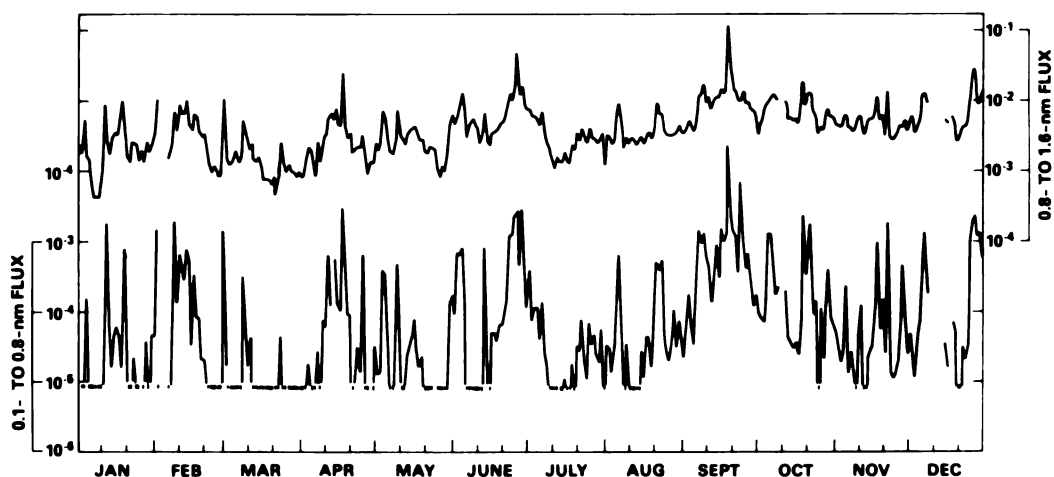


Figure 5. SOLRAD data for 1977

There were, however, several rather significant increases in June through August. The data for 1976, the year of solar minimum, are shown in Figure 4. Although regions active enough to drive the 0.1- to 0.8-nm flux levels above threshold were infrequent, there were occasional excursions up to 10^{-3} mW/m² even in this minimum period. At the beginning of June the 0.8- to 1.6-nm flux fell below the threshold level (4×10^{-4}).

The beginning of solar cycle 21 in 1977 is evidenced by the increasing x-ray levels shown in Figure 5. By May the 0.8- to 1.6-nm levels increased above 10^{-3} mW/m², and by the end of the year they approached an average value of 5×10^{-3} mW/m². Early in 1977 there were

intervals when the 0.1- to 0.8-nm flux fell below threshold, but after August this was rare. Changes by a factor of 100 occurred when active regions rotated into the disk. During most of September and October the 0.1- to 0.8-nm levels were above 10^{-4} mW/m².

Figure 6 shows that the levels for the first 6 months of 1978 were much higher than the levels of the preceding year. After February the 0.1- to 0.8-nm flux is above 10^{-3} mW/m² most of the time (and the 0.8- to 1.6-nm flux is almost continuously above 10^{-2} mW/m²). These values are comparable to the solar maximum levels of 1969.

This rapid rise in 1978 does not mean that this cycle has reached an early maximum or

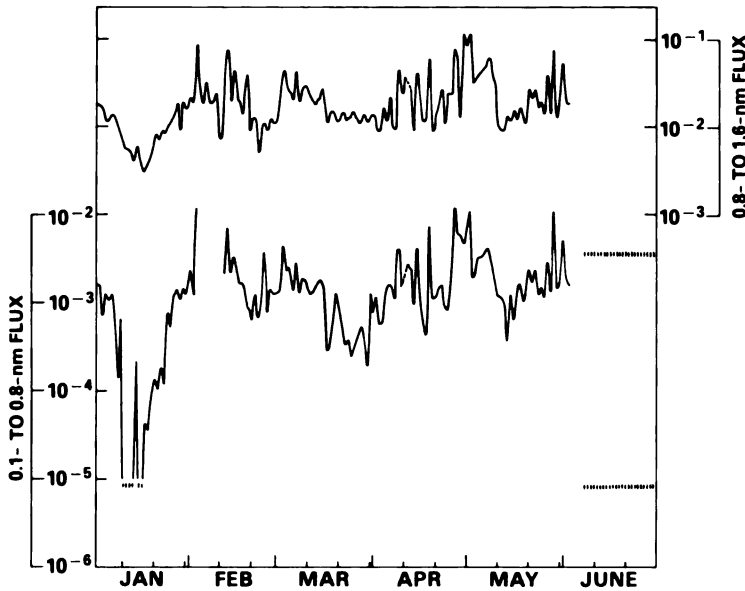


Figure 6. SOLRAD data for 1978

that it will be much more active than the last, but only that the x-ray levels reflect the great variability in solar activity. The average 0.1- to 0.8-nm flux levels can differ by a factor of 500 between solar minimum and maximum, but short-term variations can be much larger, especially when few active regions are present—that is, during the decay and rise of a solar cycle.

The historical behavior of solar x-ray flux provides important information for designers of ionosphere-dependent systems. However, the rapid variability of the x-ray flux requires that real-time data be available to support day-to-day operations of these systems.

[Sponsored by NAVAIR with NASA launch support]

HEAO 1 Discovers a New Black-Hole Candidate, by G. H. Share, K. Wood, and H. Friedman, *Space Science Division*

NRL's large-area x-ray experiment on the first High Energy Astronomy Observatory (HEAO 1) satellite was designed to survey the sky for x-ray sources fainter by as much as a factor of 10 than those previously cataloged. It was expected that new and exciting objects would be discovered, and one such discovery was made this year in analyzing data from a scan of the central region of our Galaxy.

The NRL data revealed a flickering object at the location of a previously identified x-ray source. The intensity of this source, designated as GX339-4 (galactic x-ray source at galactic longitude 339° and latitude -4°) was previously known to vary by factors of 50 or more on time scales of days or longer. The NRL experiment revealed that the source varies on time scales down to tens of milliseconds (Figures 7 and 8).

Figure 7 shows the intensity profile of GX339-4 observed with a resolution of 320 ms during three 10-s scans through the source. The separations between scans were 10 and 18 h. Flaring activity with intensity changing by a factor of 2.5 or 3 in time intervals as short as 0.32 to 1.28 s are evident.

The same source was also observed using a special mode which accumulated data in 5-ms intervals. Figure 8 shows three scans through the source plotted with a resolution of 40 ms. Flares are seen with intensity changing by a factor of 3 within 40 ms. The series of five sequential quasi-periodic flares in the center of the top scan is of particular interest. More detailed analysis has failed to reveal any persistent periodicities in the emission from GX339-4.

These temporal characteristics lead to the conclusion that GX339-4 is similar to two other x-ray objects, Cygnus X-1 and Circinus X-1,

Figure 7. Three scans through GX339-4 at a resolution of 0.32 s. The values of the source intensities are corrected for collimator response, and the background level, although shown for comparison, has been subtracted.

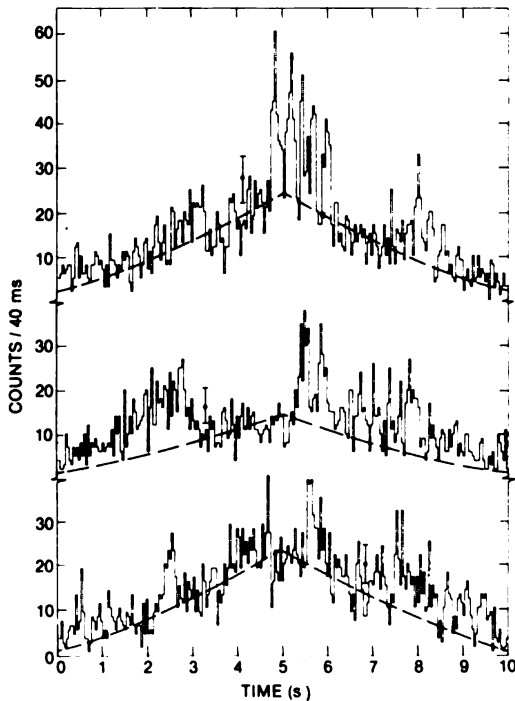
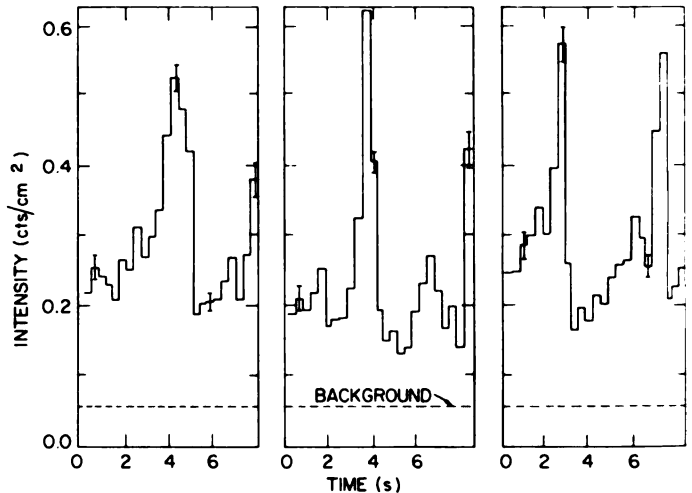


Figure 8. Three scans through GX339-4 plotted at a resolution of 40 ms. No corrections have been made to the raw data. The dashed lines show the collimator's response to a nonvarying x-ray source of limited extent.

which are believed to be binary stellar systems in which one of the objects is a black hole. The interpretations that these sources contain black holes can be inferred from measurements of the binary period of the system and the velocity and mass of the identified stellar companion.

The measurements indicate that the mass of the nonoptical compact object in Cygnus X-1 must be more than 10 times that of the Sun. The only stable state known for a compact object of this mass is a black hole. Neutron stars cannot be this massive. The x-ray emission from such exotic binary systems is believed to arise from the energy released when matter from the stellar companion is pulled into a spiraling disk around the black hole. The flickering can result from randomly occurring bursts in the disk. A shot-noise model describes these sources' aperiodic and highly variable nature.

An optical counterpart to GX339-4 has recently been found. Future observations both in the optical and x-ray wavelength regions should help to further define its properties. Two special observations of GX339-4 which were recently carried out by HEAO provide over 10 h of high-quality data for more detailed analysis.

[Sponsored by NASA]

Satellite Observations of Interstellar Helium, by C. S. Weller and R. R. Meier, *Space Science Division*

Nearby cosmic gas which fills the space between the stars (the local interstellar medium (LISM)) flows into the solar system. Until barely 8 years ago it was presumed that ionizing radiation from the Sun prevented the LISM from coming closer than several hundred times the distance from the Sun to the Earth. How-

ever, observations of the space radiation background at the characteristic ultraviolet wavelengths of hydrogen and helium, made with instruments on orbiting satellites, reveal variations in space and time that can be explained only by interstellar gas entering the solar system and absorbing and reemitting solar radiation. These observations could not have been made from Earth because of the strong atmospheric absorption at ultraviolet wavelengths.

NRL scientists obtained the first maps of the characteristic radiation from helium at 58.4 nm (584 Å) in the inflowing LISM by using an extreme-ultraviolet photometric instrument on the Earth-orbiting Space Test Program 72-1 satellite. Most recently they expanded the observations with data from a more sensitive and versatile instrument on the eighth Orbiting Solar Observatory (OSO-8).

The principal feature of the LISM helium radiation is a pronounced maximum intensity of 7.2×10^5 photons/cm²·sr·s, with a full width at half maximum of 50° in the direction of the constellation Orion and a broad minimum in the opposite direction. This is a consequence of the Sun's gravity focusing the inflowing helium into a dense, and thus bright, zone downstream of the Sun (Figure 9).

The NRL program has also developed accurate methods to compute the effects of the Sun's gravity and ionization on the trajectories and velocities of the helium atoms. Not only are the basic features of the gravitational focusing explained, but useful limits are obtained for values of the velocity, temperature, flow direction, and helium density. The LISM helium density has values in the range 0.008 to 0.02 cm⁻³; this, together with a typical cosmic helium abundance ratio of 12%, implies a hydrogen density of 0.07 to 0.17 cm⁻³. Figure 10 shows the deduced ranges of allowable values of LISM velocity and temperature, which give us our best information about the local cosmic gas. These value ranges are relatively narrow by astronomical standards.

It is interesting to speculate on the observation that, in the rest frame of the star group local to the Sun, the LISM moves in a direction close to that in which the local star group moves about the galactic center and with a speed which is 5 to 10% greater. This may be

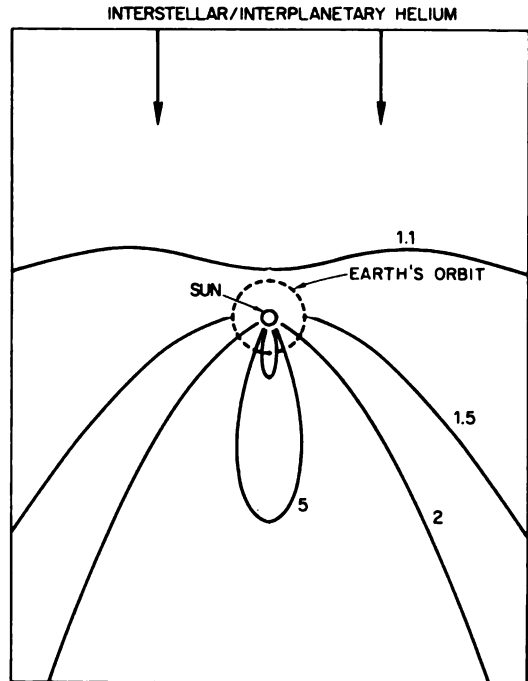


Figure 9. The distribution of helium in the vicinity of the Sun. Isodensity contours show helium density relative to the density at infinity.

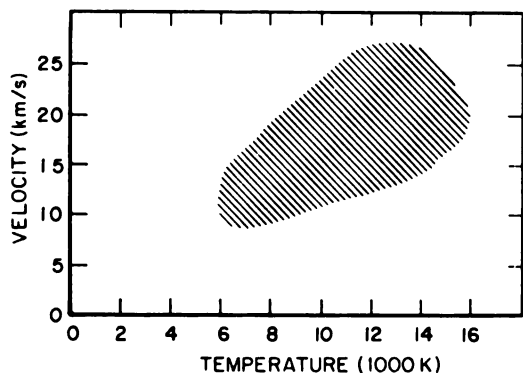


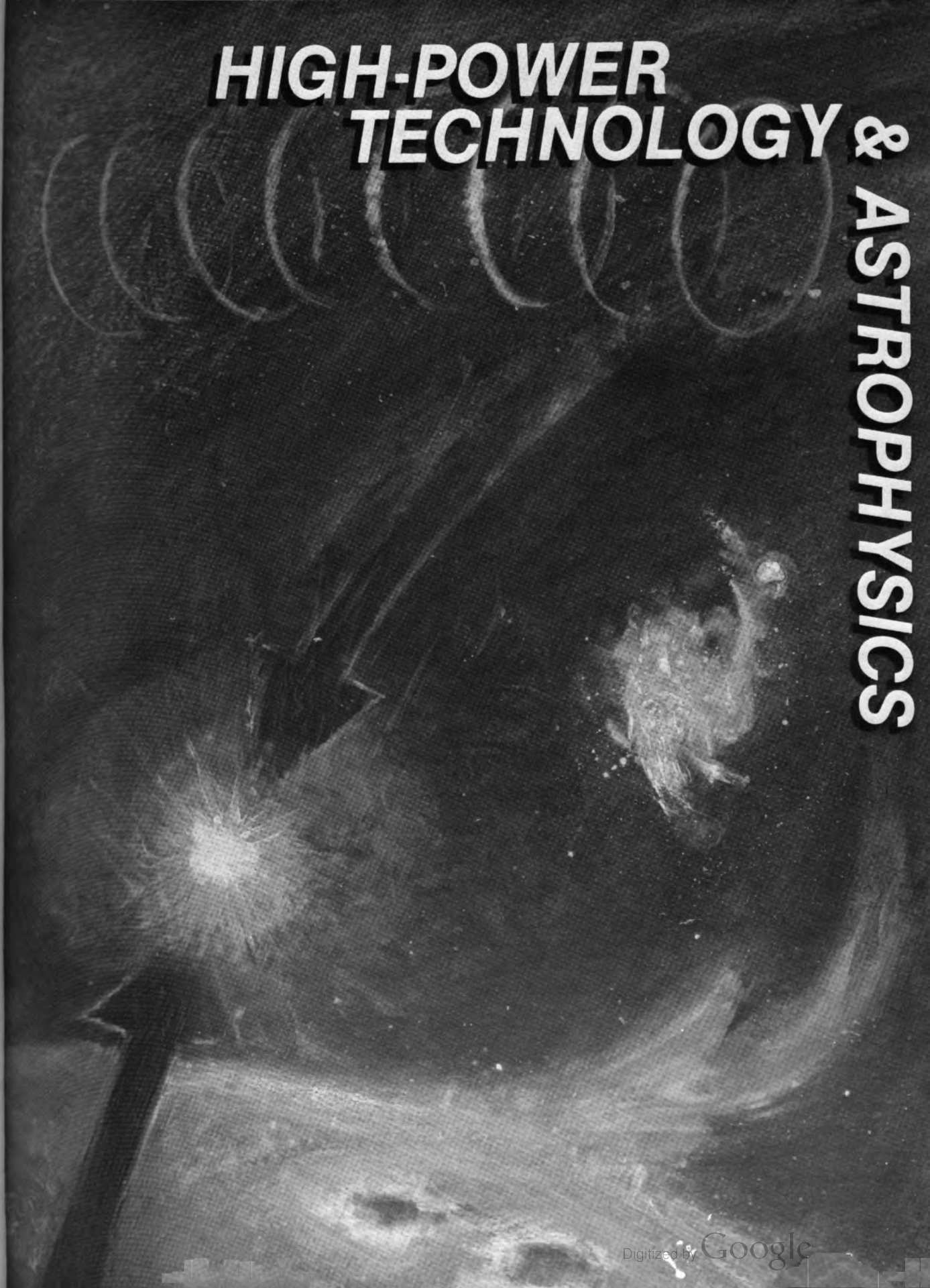
Figure 10. Allowable values of LISM velocity and temperature (hatched region) as derived from NRL analysis of ultraviolet observations from orbiting satellites

coincidence or may indicate that the interstellar medium observed locally is part of a general circulation on a much larger scale.

Future efforts will include analysis of data from the SOLRAD 11 satellites to better define the LISM parameters, and development of interferometric instruments for observing the profiles of spectrographic lines.

[Sponsored by ONR]

HIGH-POWER TECHNOLOGY & ASTROPHYSICS



HIGH-POWER TECHNOLOGY AND ASTROPHYSICS

Major new techniques for power generation, weaponry, and navigation are among the long-range objectives of work in these areas. Their ultimate realization will depend, in large measure, on basic understanding and innovative utilization of the complex, high-energy phenomena involved. NRL recognizes these major scientific and technical challenges and has continued its productive research in these areas during 1978.

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Gyrotrons: Breakthrough in Millimeter-Wave Power, by V. L. Granatstein, K. R. Chu, and P. Sprangle, *Plasma Physics Division*

The gyrotron is a new type of millimeter-wave power tube in which a beam of electrons spirals in the presence of a steady magnetic field. The electrons become bunched in phase transverse to the magnetic field and emit coherent radiation at the electron cyclotron frequency. Since the wavelength of the radiation is determined by the strength of the magnetic field and not by the dimensions of some structure in the tube, tubes of very large cross section with large power ratings can generate very short wavelength radiation.

Gyrotron oscillators have generated power levels that represent a breakthrough for microwave tubes in the wavelength range of 1 to 10 mm. Recent work at NRL emphasized the development of gyrotron amplifiers that promise to have power ratings comparable to the oscillators and that will also have superior signal-handling characteristics. This will make them much better adapted for use in communications and radar systems. During 1978, the first gyrotron traveling-wave amplifier was made operational at NRL. At a wavelength of 8 mm, a gain of 17 dB was achieved with a 10-kW output power. The measured gain is linear over an extended range (>30 dB) and agrees well with theoretical predictions. The predicted bandwidth (11%) and saturated power level (200 kW) will be tested experimentally in 1979.

Figure 1 shows the state of the art in long-pulse ($>100 \mu\text{s}$) millimeter-wave power tubes. The square data points represent power achieved in gyrotron oscillators developed in the Soviet Union and clearly constitute a marked increase in power output over that of conventional microwave tubes (shaded area in the lower left corner of the figure). NRL has also initiated a study of gyrotron oscillators and has two devices under development whose design goals are represented by the circles in Figure 1. The oscillator at 35 GHz is designed to produce 200 kW for 10 ms with 30% efficiency. As of early December 1978, this tube was in the process of being activated but had already generated 70 kW for 0.1 ms with 23% efficiency. The oscillator at 230 GHz is being fabricated from a design that predicts power generation of 4 kW with 12% efficiency.

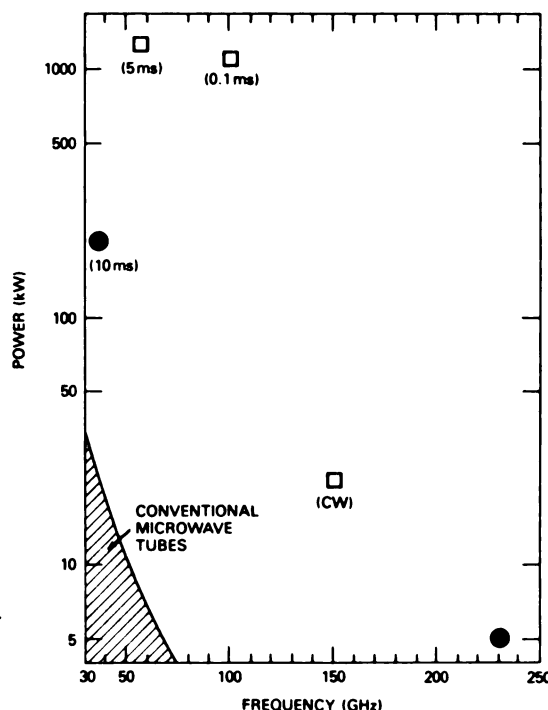


Figure 1. State of the art in long-pulse ($>100 \mu\text{s}$) millimeter-wave power tubes. Squares indicate developments in USSR; dots indicate ongoing work.

Gyrotron oscillator development is directed toward providing rf sources for heating plasmas in controlled thermonuclear fusion research. Although the gyrotron oscillator is well suited to heating applications, more sophisticated systems (*viz.* communications and radar) require wideband amplifiers. A comprehensive nonlinear theory of the gyrotron as a traveling-wave amplifier has been developed at NRL, and an amplifier has been designed to operate at 35 GHz with an optimized saturated efficiency of 51% and a corresponding saturated power level of 200 kW.

An amplifier has been constructed according to the optimized design of Figure 2. A magnetron injection gun produces a hollow beam of nearly monoenergetic electrons that follow helical trajectories around the lines of a solenoidal magnetic field supplied by a superconducting magnet. A net transfer of energy from the transverse motion of the electrons to an electromagnetic wave results from phase bunching of the electrons in their cyclotron orbits. This bunching occurs because the gyro frequency depends on the relativistic electron mass. That is, electrons that absorb energy

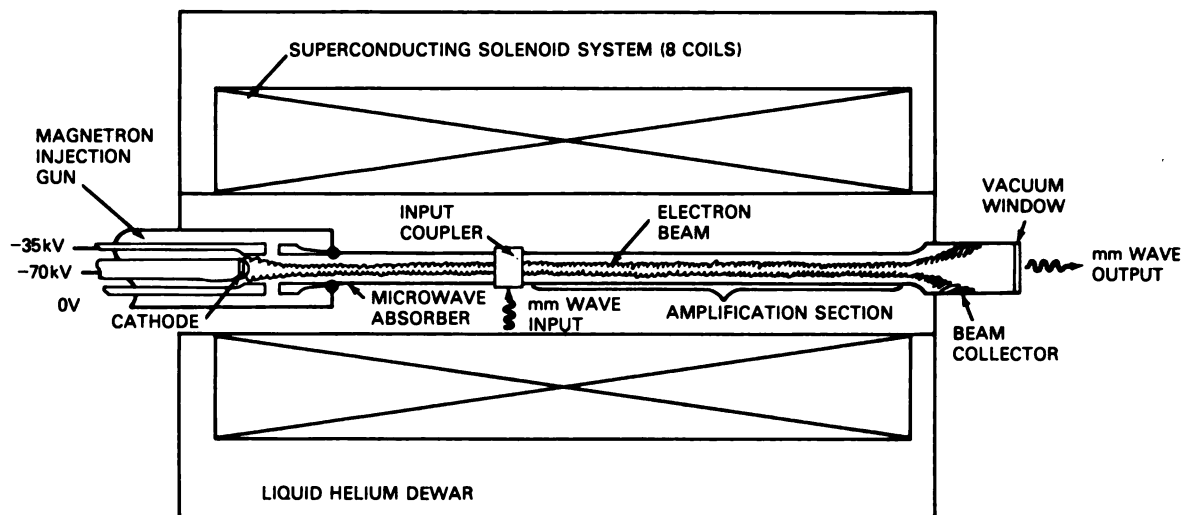


Figure 2. Gyrotron traveling-wave amplifier at 35 GHz (TE_{01} mode; length of amplification section is 17 cm; radius of annular electron beam is 2.5 mm; radius of drift tube is 5.4 mm; larmor radius is 0.61 mm)

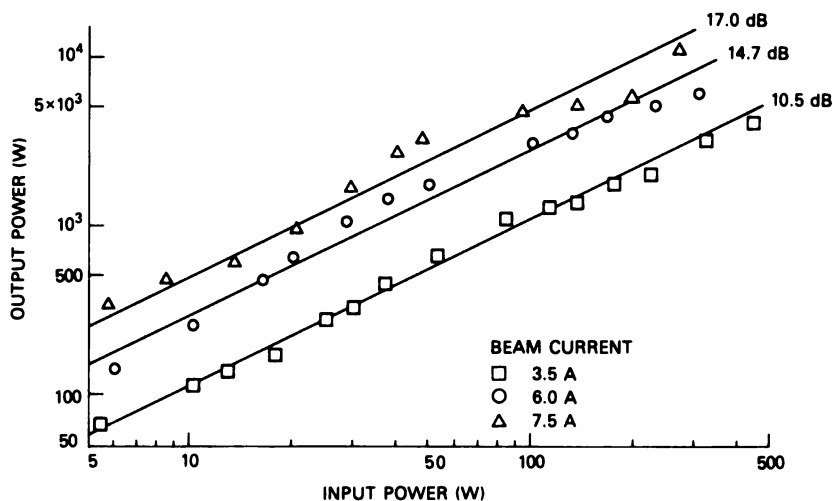


Figure 3. Gain of the gyrotron traveling-wave amplifier

become heavier and slip back in phase; conversely, those that lose energy advance in phase. The final phase distribution favors emission and amplification of the electromagnetic wave. The amplification occurs in a region of uniform axial magnetic field, $B_0 = 12.9$ kG, chosen so that the electron cyclotron frequency approximately equals the frequency of the electromagnetic wave.

The measured output power of the gyrotron traveling-wave amplifier is plotted against input power in Figure 3. The lines of constant gain that best fit the data are also plotted. The

linear gain shown in Figure 3 was found to extend over a range of at least 30 dB. Both the variation with current and the absolute value of the gain agree well with the linear theory of the gyrotron traveling-wave amplifier. With a beam current of 7.5 A, a gain of 17 dB was achieved in this single-stage amplifier with an output power of 10 kW. The amplifier has not yet been driven into saturation, nor has its bandwidth been measured because of limitations in the driver source and input coupler. These limitations will be overcome in 1979. As yet, no fundamental problems have been

observed that could prevent successful achievement of the design predictions of 200 kW of output power with good efficiency and substantial bandwidth.

Theoretical studies of other aspects of gyrotron physics have also proved fruitful. These include calculations of the operating parameters of gyrotron oscillators and amplifiers operating at harmonics of the cyclotron frequency. The results indicate, in general, that although harmonic operation does entail loss in efficiency, it also substantially reduces the magnetic field required, and may be a viable approach in systems where superconducting magnets are unacceptable. It has also been shown that the efficiency of gyrotrons can be significantly enhanced by a knowledgeable shaping of the magnetic field profile along the tube axis. In addition, a new type of "slow-wave cyclotron amplifier" is being developed at NRL which is predicted to have an instantaneous bandwidth as large as 70%.

Although still in a very early stage of development, the gyrotron promises to revolutionize millimeter-wave technology. Gyrotron oscillators are already being effectively applied to controlled thermonuclear fusion research. The first operation of a gyrotron traveling-wave amplifier described above indicates that the gyrotron amplifier may prove to be at least as important a device as the oscillator. The good agreement of measured gain with theory affords some confidence that subsequent measurements of bandwidth and saturated power level will also meet theoretical predictions. If they do, the gyrotron traveling-wave amplifier should find wide application in Navy communication and radar systems and in their civilian counterparts.

[Sponsored by NAVELECSYSCOM, BMDATC, and DoE]

Ion-Driven Thermonuclear Fusion Research,
by D. Mosher, G. Cooperstein, and S. J. Stephanakis, *Plasma Physics Division*

During the past few years, high-power generators originally designed to produce relativistic electron beams have been used to efficiently create and focus intense beams of MeV-energy protons and deuterons. Because of the favorable energy-deposition characteristics of ions in matter, these NRL experiments

were accompanied by an investigation of the use of ions to compress and heat thermonuclear pellets as a means of achieving Department of Energy (DoE) fusion reactor objectives and Department of Defense (DoD) long-range nuclear-effects simulation goals. During the past year, ongoing NRL research has demonstrated a technique for transporting the focused beam across the 2- to 5-m distance that separates the beam accelerator from the fusion pellet in a reaction chamber. Theoretical research also demonstrated that the natural combination of ion-beam pulse duration (50 to 100 ns), ion energy appropriate for fusion (2 to 5 MeV), and required transport distance allowed for "bunching" of the beam during transport. Beam bunching, a technique commonly employed in particle-accelerator research, is achieved by proper shaping of the accelerating-voltage pulse. Ions emitted late in the pulse are accelerated to higher velocity than those emitted earlier, so that the beam is concentrated in time during transport to the pellet. The ion beam incident on the pellet is therefore shorter but at a much higher power than that emitted by the accelerator. Since as much as a tenfold power increase may be achieved by this technique, existing pulsed-power generators might be useful for driving the thermonuclear implosion of pellets.

Figure 4 illustrates the technique for delivery of a focused ion beam to the pellet. A combination of electrode shaping and magnetic bending of the ion orbits in the diode causes the emitted ion beam to be focused a few tens of centimeters in front of the diode. The focusing region beyond the vacuum diode is filled with a low-pressure (1 to 10 Torr) gas that neutralizes the beam's self-magnetic fields. Otherwise, the unneutralized fields can deflect ions away from the focus in a manner that cannot easily be compensated for by diode shaping. At the focus, the beam enters a current-carrying plasma channel established about 10 μ s before ion injection by the discharge of a capacitor bank. The magnetic field associated with the 25- to 150-kA channel current confines the beam and guides it to the pellet.

Preliminary channel transport experiments have been carried out on the NRL Gamble I pulsed-power generator using a focused beam

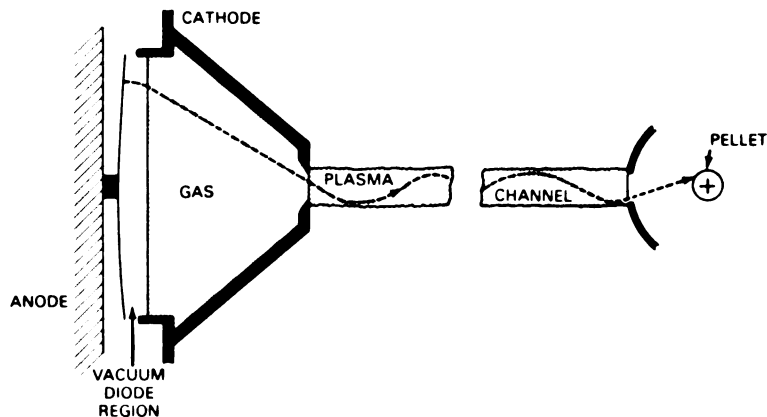


Figure 4. Technique for delivery of a focused ion beam to a thermonuclear pellet. Ions created in the vacuum diode region come to focus in a gas-filled region. At focus, the ions enter the plasma channel (channel current = 25 to 150 kA). The magnetic field within the plasma channel confines the focused ion beam, guiding it to the 1-cm-diameter pellet. (Not drawn to scale.)

of 0.5-MeV ions injected into a discharge channel that was 1 m in length and 1.5 cm in diameter. The discharge occurred inside an insulating tube defining the 1.5-cm channel diameter. Beam diagnosis utilized the gamma rays produced by interaction of the fast ions with fluorine in a Teflon target that was placed at various distances along the channel. Some results are shown in Figure 5. All three traces show an initial, small signal associated with x rays produced by electrons in the diode. For the top two traces, the target was 27 cm inside the tube (i.e., near the front of the transport section). With zero discharge current in the tube (trace A), only the x-ray signature of the diode is observed. In trace B, with identical conditions except for the application of channel current, ion transport is demonstrated by the observed ion signal. For trace C, the target was placed at the far end of the current-carrying channel, and it is clear that ions are transported the 1-m length. The ion signal at 1 m is delayed by a time equal to the ion time of flight to the target. These preliminary experiments demonstrate that an initially focused beam can be transported using a narrow z-discharge channel.

Figure 6 illustrates the increase in power due to bunching during beam transport as calculated by computer for generator, beam, and transport channel conditions appropriate to a reactor. It has been determined that the range of ion-injection angles (θ_m) into the channel

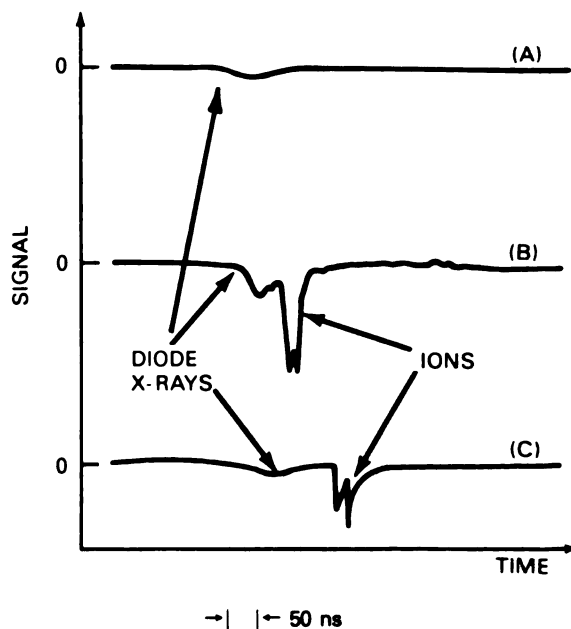


Figure 5. Gamma-ray signals produced by interaction of an ion beam with Teflon target in the transport discharge tube. With zero channel current trace A shows only the diode x-ray signal. Traces B and C (targets at 27 cm and 100 cm, respectively, within the tube) clearly indicate ion transport when a 40-kA channel current is applied.

limits power multiplication. Although superior for bunching, small injection angles require long focusing distances with a possible loss in the quality of focus. Both present experiments and reactor scenarios operate with $\theta_m \approx 0.2$ radians so that power multiplication of one order of magnitude may be achievable. Thus,

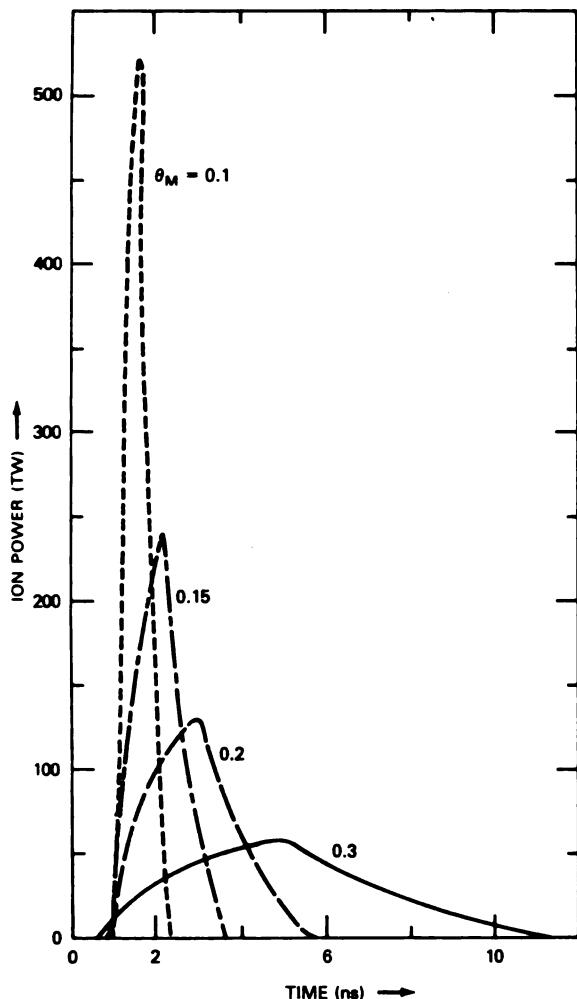


Figure 6. Theoretical calculation showing the increase in ion power and associated decrease in pulse duration afforded by bunching during transport. The beam emerging from the accelerator has a power of 10 TW and lasts 50 ns. The power multiplication factor varies inversely as the square of θ_m , the maximum injection angle (in radians) of ions into the channel.

if 100 TW is required to ignite a fusion target, accelerators producing a total beam power of about 20 TW may be sufficient. This can be achieved with about six state-of-the-art accelerator modules. Therefore, light ion beams may provide a quickly realizable, modestly priced means for achieving DoE fusion reactor and DoD advanced simulator objectives.

During the next few months, focusing and transport experiments will be conducted on the newly upgraded NRL Gamble II accelerator at an ion current level equal to that required for a reactor module but with only 1/2 to 1/3 of

the voltage. To date, 500 kA of 1.4-MeV protons (representing a 50% ion power efficiency) have been extracted from this device. Deuterons have been focused to nearly 200 kA/cm². Previous experiments at one-third the present power level have demonstrated that a beam of 120-cm² cross-sectional area can be focused with greater than 50% efficiency down to 2 cm², an area approaching that of a fusion pellet or transport channel. Experiments on larger accelerators outside the Laboratory are planned for 1979.

[Sponsored by DNA/DoE, ICF Office]

LINUS: Stabilized-Liner Implosion Research, by P. J. Turchi, *Plasma Physics Division*

It has been recognized for some time that very compact electrical power sources would be possible if energy density and pressure levels could be extended beyond limits set by strength of materials. Devices that utilize extremely high pressures and produce high-energy, high-power electrical pulses are the so-called magnetocumulative or explosive generators. In such generators, high explosives (HE) are typically used to force electrical conductors together at speeds of a few thousand meters per second, so that magnetic flux trapped between the conductors is compressed into a smaller area. Ultrahigh magnetic fields (up to 2500 tesla) are generated by such magnetic flux compression. These fields exert pressure against the moving electrical conductors, converting the kinetic energy of the conductors into electromagnetic energy. The extremely high pressures associated with HE detonation and the debris from solid conductors colliding at speeds of kilometers per second result in destruction of the generator, at least locally, so that only single-shot operation is possible. A principal aim of the liner implosion research at NRL has been to develop methods of utilizing magnetic-flux-compression techniques that will allow controlled, safe, repetitive operation. These methods will then be applied to such problem areas as compression of controlled thermonuclear fusion plasmas for continuous power generation, flux compression for pulsed electrical power generation, compression of particle beams to high energy, and acceleration of projectiles to hypervelocities.

Experiments at NRL with electromagnetically imploded aluminum cylinders or liners (26 to 28 cm I.D., 7 cm long, 1 mm thick) successfully demonstrated the use of nonexplosive driving techniques to implode large electrically conducting shells at high speeds (1.4 km/s). Peak fields up to 1.4 MG were obtained, with radial implosion ratios of 30:1. Liquid sodium-potassium liners (24 cm I.D., 7 cm long, 1 cm thick) were also imploded electromagnetically and demonstrated, for the first time, the use of liner rotation to stabilize the inner surface of the liner during its reversal of motion at peak compression. Normally, an accelerating interface between two fluids of different mass density is unstable to small perturbations if the acceleration vector points toward the fluid of higher mass density. Without sufficient rotation (centripetal acceleration greater than radial acceleration), the inner surface would break up during the final stages of compression, possibly destroying the high-energy density of the compressed payload (high-temperature plasma, high-energy ion ring, *etc.*). A similar disruption of the liquid liner will occur at the outer surface as it is accelerated inward by magnetic fields or high-pressure gas. Rotation does not prevent this since the centripetal acceleration points toward the fluid of higher mass density. Instead, a solid free piston (discussed below) is

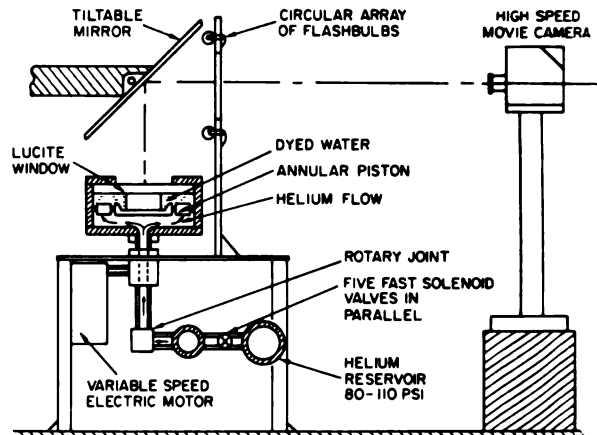


Figure 7. Hydrodynamic model experiment for stabilized liquid-liner implosions. Axis of rotation is vertical, and annular piston plate moves axially upward, which causes the radial implosion of the inner free surface of the rotating liquid liner. Initial surface diameter is 10 cm.

used to transfer the pressure between the driving fluid (gas or magnetic field) and the liner, thereby eliminating the free interface between fluids of different mass density.

With the inner and outer surfaces of the liquid liner controlled by rotation and free-piston drive, respectively, the motion of the liner should be nearly reversible. Figure 7 is a schematic of an experimental model of a controlled liquid liner implosion system. High-pressure (~ 2 MPa) helium drives an annular

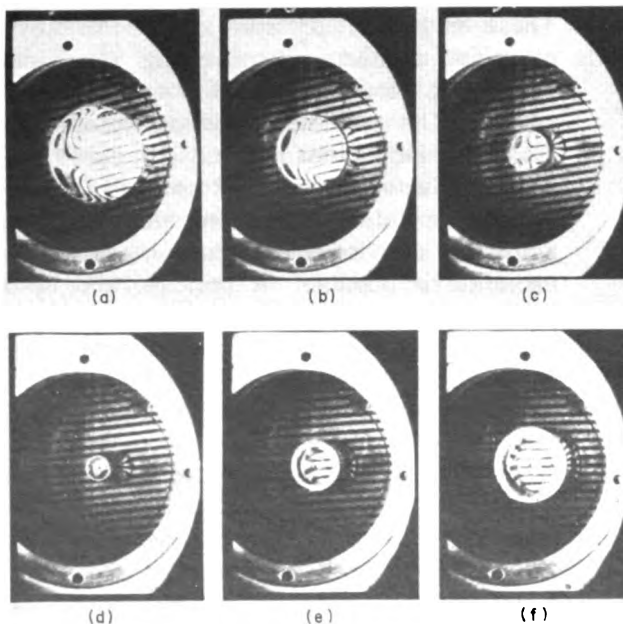


Figure 8. Sequence of high-speed photographs of the stabilized implosion and reexpansion of a rotating liquid liner driven by axial displacement of an annular free piston. Implosion quality and stability are such that a line pattern on the bottom of the implosion chamber is reflected off the inner liner surface throughout the implosion and reexpansion phases. Compression (a,b,c) is maximum at (d) and is followed by reexpansion (e,f). Initial surface diameter is 10 cm; time between frames is 420 μ s.

free piston parallel to the axis of rotation, thereby forcing the free cylindrical inner surface of a water liner (10-cm initial diameter) to implode radially onto a trapped volume of air. Hydrodynamically, this simulates the implosion of liquid metal liner onto trapped magnetic flux. Figure 8 is a sequence of high-speed movie photographs of such a water liner implosion. With the camera looking down at a slight angle to the system axis, a pattern of lines on the bottom of the implosion chamber is reflected off the inside and outside surfaces of the liner during the complete implosion and reexpansion of the liner. As predicted by theory, if rotation is insufficient as the liner decelerates and reverses direction, it will destroy the optical quality of the inner surface.

During fiscal 1978, two new controlled-implosion systems, LINUS-O and HELIUS, were constructed to extend operation to much higher pressure levels. In the larger device, LINUS-O, explosive-product gases (at pressures to 30 MPa) drive 30-cm initial-surface diameter liners of either water or sodium-potassium alloy (NaK) to peak pressures of 1000 MP. HELIUS, a half-scale version of LINUS-O, is driven by high-pressure helium (up to 12 MPa). Both devices have begun operation at lower drive pressures. With these systems, NRL possesses unique facilities to study the physics and engineering of controlled high-energy-density implosions and to apply such implosions to the development of advanced electrical power sources and new weapons systems.

[Sponsored by ONR and DoE/ETM]

Experimental Beam Plasma Discharge Studies, by E. P. Szuszcwicz and D. N. Walker, *Space Science Division*

Beam plasma discharge (BPD) is a term used to denote the condition of enhanced ionization which results from the interaction as a beam of cold electrons (with energies lower than those of ambient particles) propagates through a weakly ionized plasma. Specific characteristics of BPD are large increases in electron density, intense RF emission, and significant velocity spreading of the initial beam. The phenomenon has a significant impact in many space experiments. For exam-

ple, during an electron-beam experiment in space, an electric charge will build up on the spacecraft, and various experiments will be affected. Collective effects due to BPD can also arise during laboratory beam injections into neutral-gas and charged-particle environments.

To help in understanding the basic physical processes involved, NRL scientists recently participated in a series of beam-plasma experiments conducted in the large vacuum chamber at the Johnson Space Center (JSC), Houston. With plans for space shuttle beam-accelerator experiments directed at controlled beam-plasma interactions, and with the use of beams to probe plasmas in general, it becomes increasingly important to be able to predict the effects of BPD. The NRL contribution to this series of experiments involved the measurement of electron density (N_e), temperature (T_e), and density variation power spectra ($\delta N_e(\omega)$) under varying conditions of plasma disturbance. These efforts provided the first N_e and T_e profiles obtained in a large vacuum chamber under conditions of BPD.

The primary diagnostic tool employed in determining N_e and T_e was the NRL pulsed plasma probe (P^3). Because the P^3 uses an electronic pulsing technique, it is particularly well suited to environments that involve dynamic plasma states and possible electrode-surface contamination. This is so because the P^3 technique effectively eliminates hysteresis and the problems of varying contact potential which plague conventional Langmuir probes and could have caused problems in this experimental series.

A typical experimental configuration is illustrated in Figure 9. The P^3 was mounted on a traversal mechanism positioned approximately 8 m above the injection point of the beam. BPD was established with an appropriate vacuum, magnetic field, and electron-gun current and voltage, and the probe was traversed to determine the plasma's radial profile out to 4.6 m. The resulting measurements of T_e and N_e are presented in Figure 10.

From comparison of a simple two-dimensional diffusion model with the experimental results (as done in Figure 10) the electron diffusion coefficient perpendicular to the magnetic field was calculated. The coefficient was found to be orders of magnitude larger

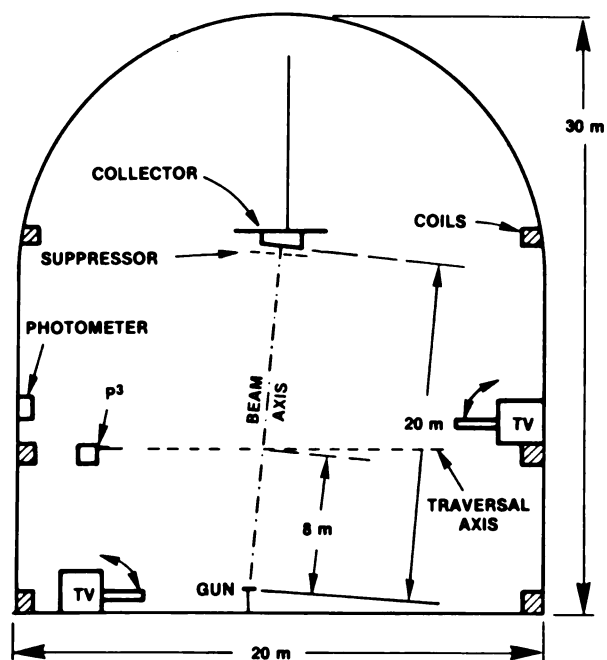


Figure 9. Typical NRL experimental configuration in the large vacuum chamber at Johnson Space Center. The pulsed plasma probe (P^3) was used in measuring the radial temperature and density profiles under conditions in which a beam plasma discharge (BPD) exists.

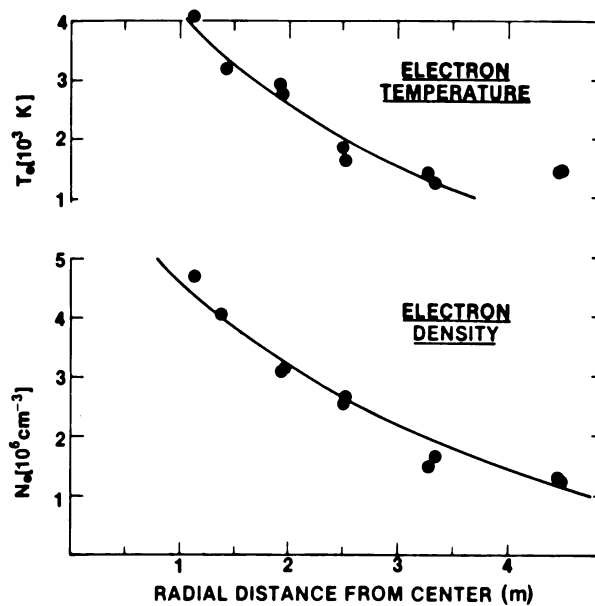


Figure 10. Electron density and temperature measurements and theoretical profile fits: $N_e = 7.01(-r/2.49)$ and $T_e = 6.93 \exp(-r/1.99)$

than that to be expected for collisional diffusion alone. This is not surprising, since one characteristic of BPD is the presence of fluctuating electric fields associated with large-amplitude plasma waves. The presence of such fields can considerably enhance crossfield diffusion above collisional diffusion. In that situation the Bohm diffusion coefficient is a more appropriate basis for comparison and is, in fact, of the same order of magnitude as the calculated diffusion coefficient. A more complete description of the turbulent-plasma-state diffusion requires consideration of electron-density-fluctuation power spectra and associated stability processes. Such work is under way at NRL.

The ability to predict the onset of BPD as a function of plasma parameters, beam energy, and boundary conditions is a necessary step in understanding interactions of electron beams and plasma in space. Perhaps, for example, careful scrutiny of the power spectra of plasma-density variations might reveal a precursor to the onset of BPD. In any case the NRL experimental efforts have provided a useful first set of diagnostic data from which to proceed to further study at JSC and ultimately to space-shuttle applications.

[Sponsored by ONR]

The X-Ray Spectrum of the Crab Nebula, by M. S. Strickman, J. D. Kurfess, and W. N. Johnson, *Space Science Division*

The Crab Nebula supernova remnant provides astronomers with the opportunity to observe, within the galaxy, high-energy processes similar to those occurring in extremely active extragalactic radio sources. Furthermore, the steady x-ray output of the Crab has served as a standard candle for x-ray astronomy.

The Crab was recently observed with a balloon-borne, hard-x-ray observatory designed and built at NRL. The x-ray detector, consisting of a sandwich of NaI and CsI scintillation crystals, responds to x-ray energies between 15 keV and 250 keV and, with a detection area of 765 cm², is much more sensitive than the instrumentation of previous experiments in this energy range. The high sensitivity demands great care in the analysis. In particular, the

energy and time-dependent responses of the detector must be very well understood, or systematic errors will dominate the measurements. Therefore, a combination of laboratory measurements and detailed Monte Carlo simulations were employed to model instrumental response.

The Crab x-ray spectrum has been observed over a wide range of energies and is generally consistent with a single power-law model with spectral index -2 (the number of x-ray photons with energies around the value E is approximately $6.5E^{-2}$ photons/cm²·s·keV). However, the results of the NRL experiment are not consistent with a single power-law model. Instead, the observed nebular spectrum steepens at approximately 80 keV, with the spectral index changing from -1.99 ± 0.06 to -2.42 ± 0.09 (Figure 11).

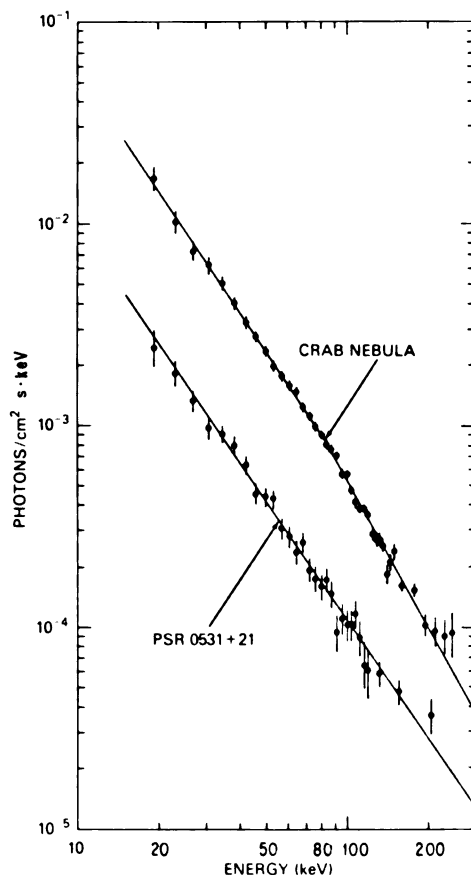


Figure 11. The hard x-ray spectrum of the Crab Nebula, shown with the best two-power-law fit, and the spectrum of the pulsar (PSR0531+21) in the nebula, shown with the best single-power-law fit

The Crab radiates x rays by the synchrotron mechanism (emission from electrons accelerated in circular orbits by a magnetic field). Therefore, the spectrum of the radiating electrons can be deduced from the photon spectrum if the magnetic field is known. A number of independent estimating techniques all lead to estimates of the nebular magnetic field strength near 50 nanoteslas (0.0005 gauss). With use of this estimate, the steepening of the photon spectrum infers a steepening or cutoff of the nebular electron spectrum at approximately 10^{14} eV. The electrons are presumed to have been accelerated by PSR0531+21, the pulsar in the center of the nebula, whose x-ray spectrum is shown in Figure 11. Pulsar theory predicts a maximum accelerated-electron energy near 10^{14} eV. Hence, the observed x-ray data confirm the connection between the pulsar and the nebular x-ray emission and support existing pulsar theory.

Further analysis of the change in power-law index will yield additional information on the processes by which the accelerated electrons interact with the nebula. However, detailed study of these processes requires instruments with high spectral sensitivity and angular resolution. Current detectors, which integrate over the entire nebula, cannot directly observe the processes by which electrons lose energy as they propagate through the nebula. Instruments with the angular resolution required for observing these processes are being developed at NRL and elsewhere.

[Sponsored by ONR]

Rocket Ultraviolet Spectra of Cygnus Stars, by G. R. Carruthers, H. M. Heckathorn, and C. B. Opal, *Space Science Division*

An NRL far-ultraviolet electrographic stellar spectrograph was flown on a NASA Astrobee-F sounding rocket on May 15, 1978. Spectra of hot stars in Cygnus were obtained over the wavelength range 95 to 200 nm (950 to 2000 Å) with high photometric quality. The principal objective was to accurately determine relative and absolute ultraviolet flux distributions (intensity vs wavelength) for the observed stars. Accurate photometry and spectrophotometry are important to military applications as well as to scientific investigations in the ultra-

violet region of the spectrum. Accurate measurement of the spectral distributions of selected stars allows them to be used as reference standards in other ultraviolet imaging and spectrographic investigations.

The rocket spectrograph (Figure 12(a)) was based on a large electrographic Schmidt camera (NRL's 1976 Review) which was previously flown in October 1976 to obtain far-ultraviolet imagery of the Andromeda Galaxy and of the North America Nebula in Cygnus. This time the camera was equipped with an objective grating to provide spectral dispersion, and an annular aperture replaced the Schmidt corrector to obtain spectra down to 95 nm. Although other instruments have covered this wavelength range in stellar spectra, most notably the Princeton University spectrometer on the NASA OAO-3 satellite *Copernicus*, a need remained for accurate measurements of absolute and relative spectral intensities, particularly in the wavelength range below about 130 nm.

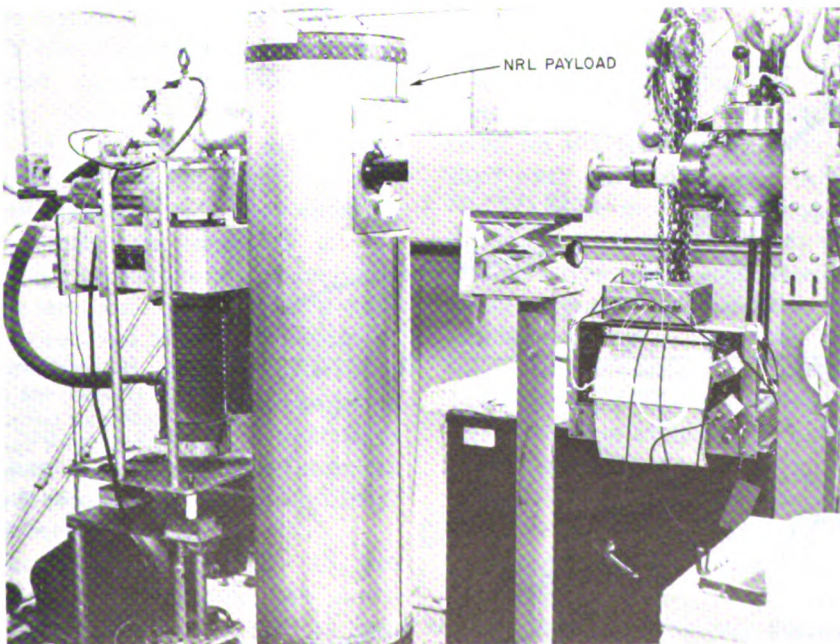
The rocket instrument was calibrated before launch using the synchrotron storage ring ultraviolet light source, SURF-II, at the National Bureau of Standards. Figure 12(b) shows the setup of the rocket payload on the NBS SURF-II facility, where calibration spectra were obtained only 10 days before the launch from the White Sands Missile Range. Synchrotron storage ring light sources have several important attributes as spectral intensity standards. In particular, the spectral distribution of the ultraviolet radiation is accurately predictable if the energy of the circulating electrons is known, the absolute intensity of the radiation is accurately predictable if the number of circulating electrons is known, and the spectral intensity distribution increases toward shorter wavelengths in the ultraviolet spectral range of interest in a way similar to that found in the spectra of hot stars. The electrographic camera is well suited to absolute spectrophotometry because of its linear and reproducible response, its wide dynamic range, and its use of fine-grained, low-background-fog recording emulsions.

Figure 13 shows an objective spectrogram of the Cygnus star field with spectra of more than 40 stars (some as faint as the 8th visual magnitude) appearing in this 70-s exposure. Figure 14 shows microdensitometer tracings of



Figure 12(a). David King of NRL preparing the electrographic Schmidt spectrograph for the rocket flight

(a)



(b)

Figure 12(b). Electrographic Schmidt spectrograph in a rocket-payload setup during calibration at the National Bureau of Standards

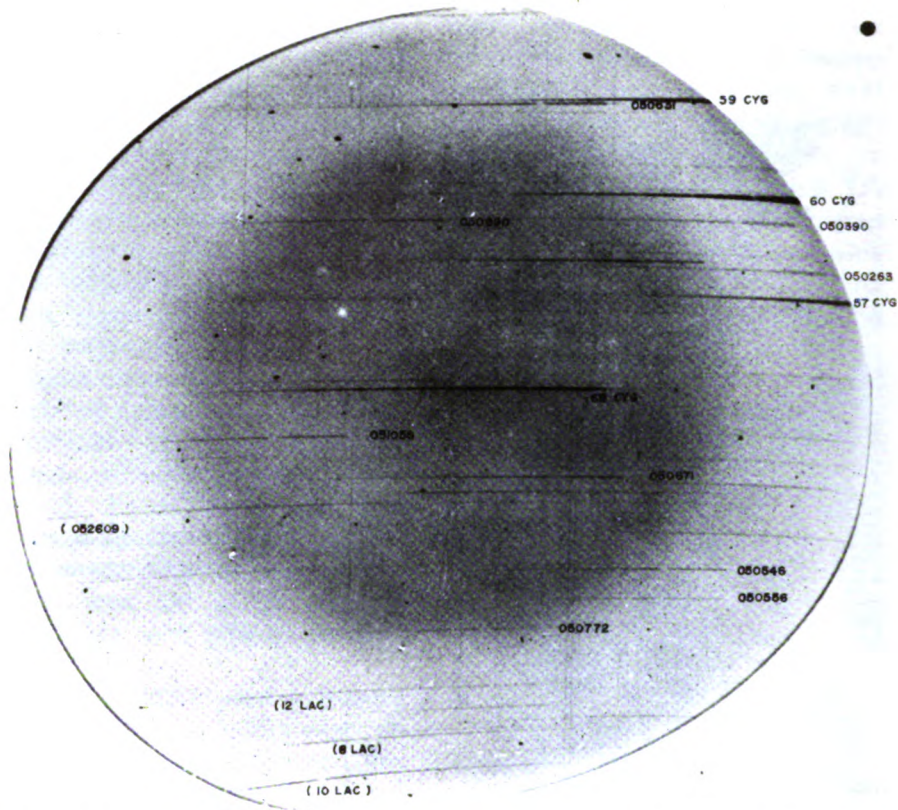


Figure 13. Objective spectrogram of an 11°-diameter field centered near the star 68 Cygni. The six-digit numbers are identifications from the Smithsonian Astrophysical Observatory Star Catalog. The wavelength range is 95 to 200 nm, increasing from right to left in each spectrum. The strongest absorption feature in each spectrum is due to atomic hydrogen at 121.6 nm wavelength.

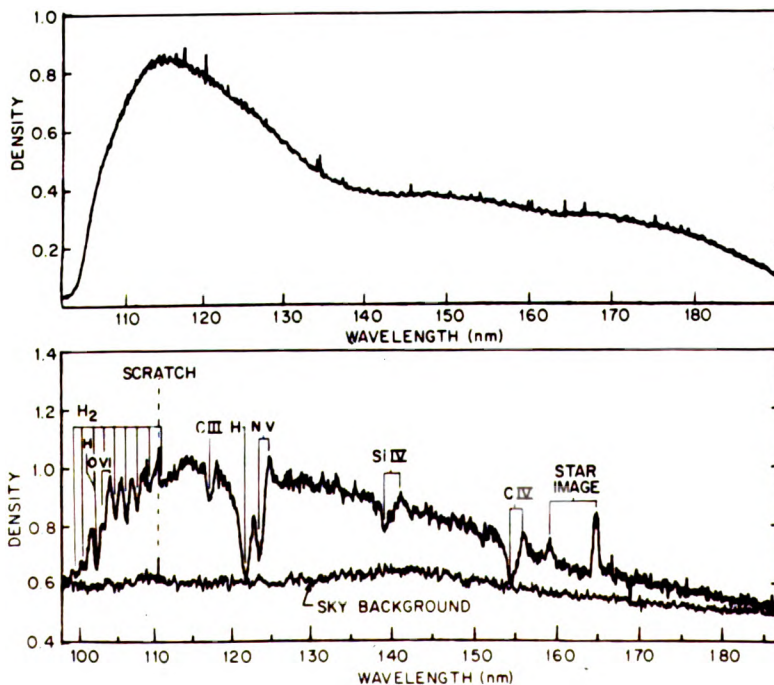


Figure 14. Microdensitometer tracings of spectra obtained with the rocket instrument: (top) calibration spectrum obtained by use of the NBS SURF-II synchrotron storage ring (30-s exposure); (bottom) flight spectrum of the star 68 Cygni (70-s exposure) with some prominent features identified

a SURF-II calibration spectrum and of a flight spectrum of the star 68 Cygni. A lithium fluoride window, opaque to wavelengths shorter than 105 nm, had to be used in the beam line during the SURF calibrations in order to maintain the vacuum conditions that the storage ring requires. The transmission of this window at wavelengths longer than 105 nm was measured separately at NRL. The calibration of the spectrograph was extended from the LiF cutoff to wavelengths shorter than 95 nm in a separate calibration at NRL, using a windowless channel photomultiplier as a transfer standard. Analyses of these data are in progress.

[Sponsored by ONR and NASA]

Imagery of Ionized Gas in a Supernova Remnant, by S. D. Shulman and H. M. Heckathorn, *Space Science Division*

A fast wide-field camera was developed and used to obtain monochromatic (single-wavelength) images of faint extended astronomical objects such as diffuse emission nebulae. These objects are composed of low-density gases heated either by hot young stars in regions where stars are forming, or by the explosions of old stars usually referred to as supernovae. The camera provides ground-based imagery at visible wavelengths to complement the far-UV observations with NRL's electrographic Schmidt cameras discussed in the preceding article. In addition the camera is used to search for faint emission nebulosities which may be detectable as the optical counterparts of extended regions of soft-x-ray emission and to image supernova remnants at the wavelengths of high-excitation-energy emission lines. These images are then compared with the morphology observed at x-ray wavelengths and at the wavelengths of lower-excitation-energy emissions. Since different emission lines are dominant at different temperatures and densities, these studies provide information on the prevailing physical conditions and heating mechanisms within these objects.

The camera shown in Figure 15 was assembled at NRL by combining fast short-focal-length lenses (catadioptric optical systems) with an existing electrographic image tube. In this configuration it can record an intensified image of a large area of the sky (up

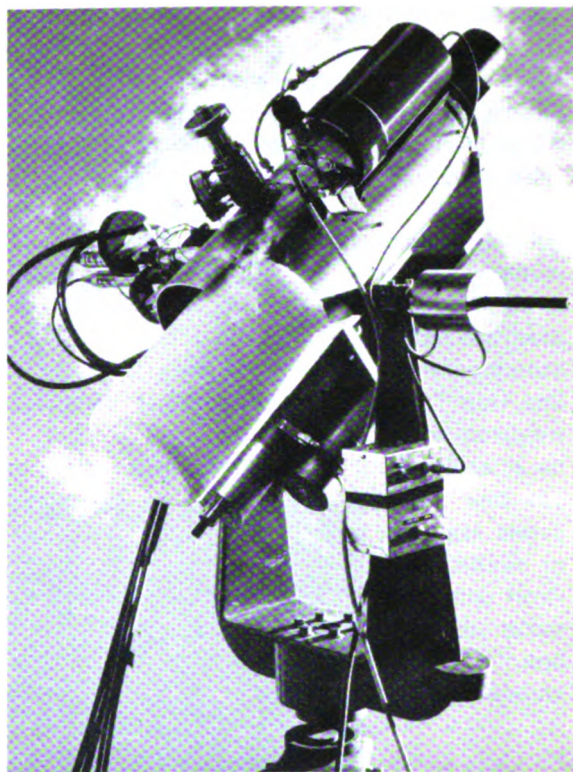


Figure 15. Electrographic image tube developed by Dr. Gerald Kron of the U.S. Naval Observatory and adapted by NRL scientists for use in wide-field astronomical imagery

to 150 square degrees) in a single exposure. The images are obtained through narrow-bandwidth (2.5-nm) interference filters centered on the spectral emission line of interest such as forbidden O^{+2} ($\lambda 500.7$ nm) or Ne^{+4} ($\lambda 342.6$ nm). The scene is focused onto the image-tube photocathode, and the resulting photoelectrons are accelerated and reimaged directly onto a nuclear-track emulsion. This emulsion is kept at liquid-nitrogen temperature to prevent the release of contaminants which would irrevocably damage the photocathode. The recording emulsion is extracted from the camera by the use of an all-metallic gate valve, which allows the highly reactive photocathode to be maintained in an ultrahigh vacuum for subsequent reuse. Conventional photographic development techniques are used.

Among the advantages of the electrographic image-tube system are high quantum efficiency in detection (each photoelectron blackens at least one silver grain), linearity over

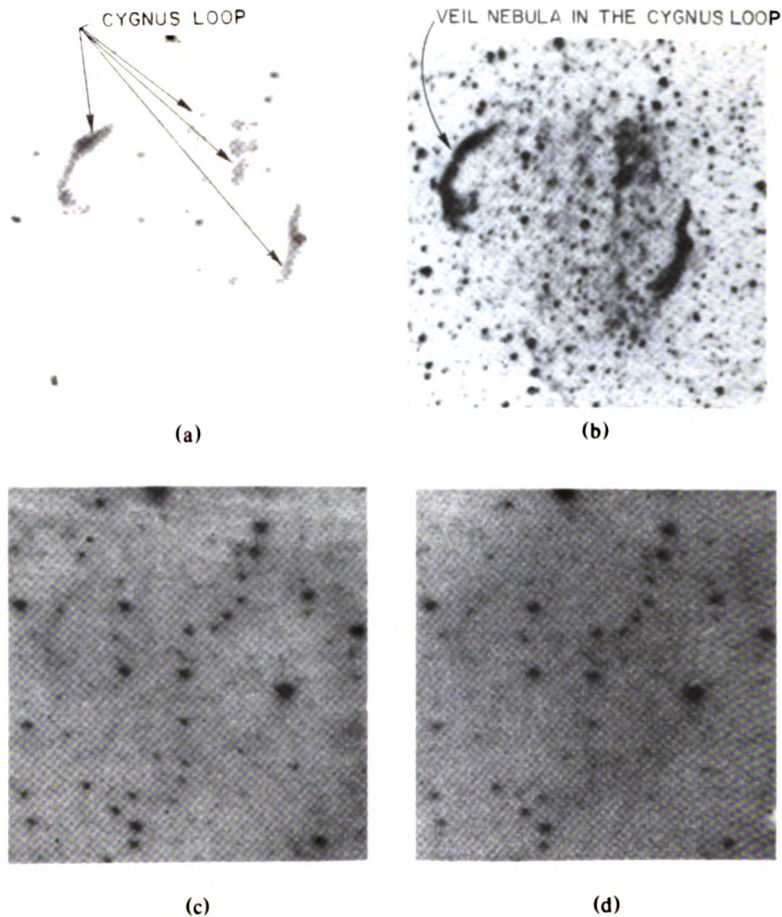
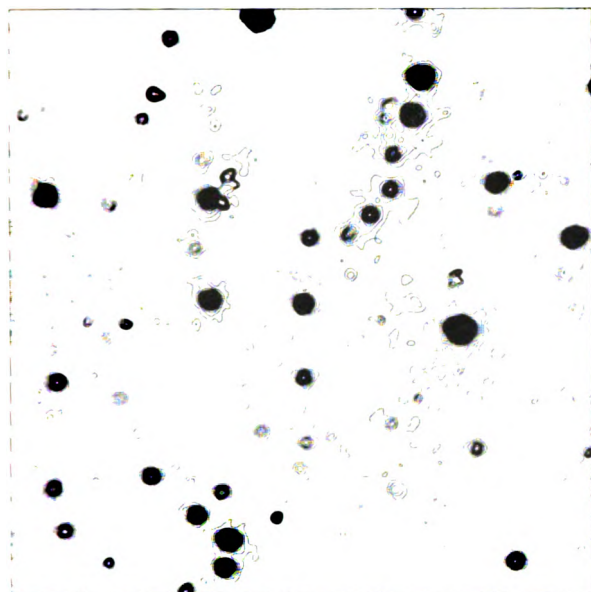


Figure 16. Electrographic images of the Cygnus Loop supernova remnant in three emission lines: (a) at 372.7 nm (O^{+1}), exposed 50 min., (b) at 500.7 nm (O^{+2}), exposed 60 min., (c) at 342.6 nm (Ne^{+4}), exposed 720 min., and (d) in a spectral region devoid of strong emission at 350.9 nm, exposed 82 min. The Ne^{+4} image is the result of superposing six individual images with an accumulated exposure time of 12 h. North is up, and east is to the left.

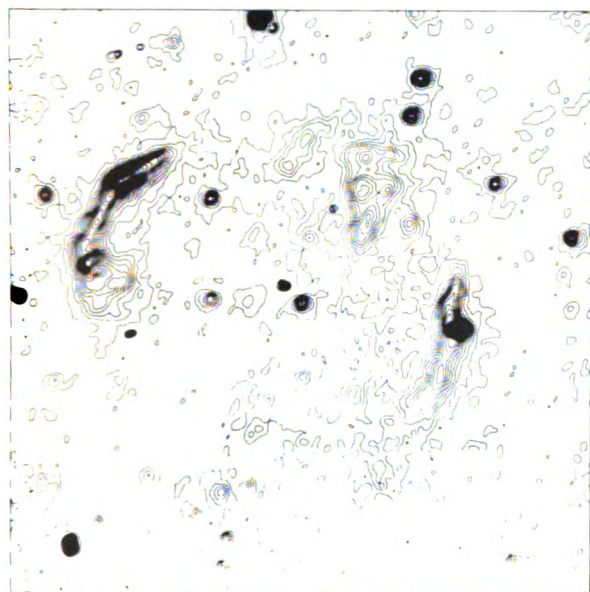
a wide range of exposure levels, and low instrumental background. These characteristics permit low-contrast features to be revealed in the resulting images. Contrast is always a problem when photographing a diffuse nebula, because the night sky and the myriad of unresolved faint stars also emit a continuum, part of which is transmitted through the bandpass of the interference filter. In fact, the luminosity of the night sky is the principal source of background in the imagery. Hence the actual observations are made under the dark nighttime sky of McDonald Observatory in western Texas. Prior to observations the system is tested, cali-

brated, and modified if necessary at NRL. The microdensitometry, computerized data reduction, and scientific analysis of the resulting images are also done at NRL.

The camera was completed early in 1978 and, during the spring, electrographic images of the Cygnus Loop supernova remnant were obtained in four passbands with this system (Figure 16). Of particular interest is the imagery at $\lambda 342.6$ nm, a forbidden line of quadruply ionized neon which is produced at temperatures in the range 200 000 to 500 000 K. A diffuse low-surface-brightness feature can be faintly seen corresponding in position, shape,



(a)



(b)

Figure 17. Isophotal contour maps of the Cygnus Loop (a) at 342.6 nm (Ne^{+4}) and (b) at 372.7 nm (O^{+1}) generated from densitometry and computer analysis of the imagery in Figure 16. Note the similarity of structure of the Veil Nebula (diffuse object in the upper-left-hand corner) in these two emission lines, which are formed in entirely different temperature regions.

and orientation to the Veil Nebula on the northeast rim of the Cygnus Loop. Careful densitometry and computer analysis were applied to the imagery to reveal this feature

more clearly as is shown in the isophotal contour plot of Figure 17(a). The maximum surface brightness of the nebula in this neon emission line is 8% of the night-sky background through the same filter. Features as faint as 2% can be clearly distinguished in the computer-processed imagery.

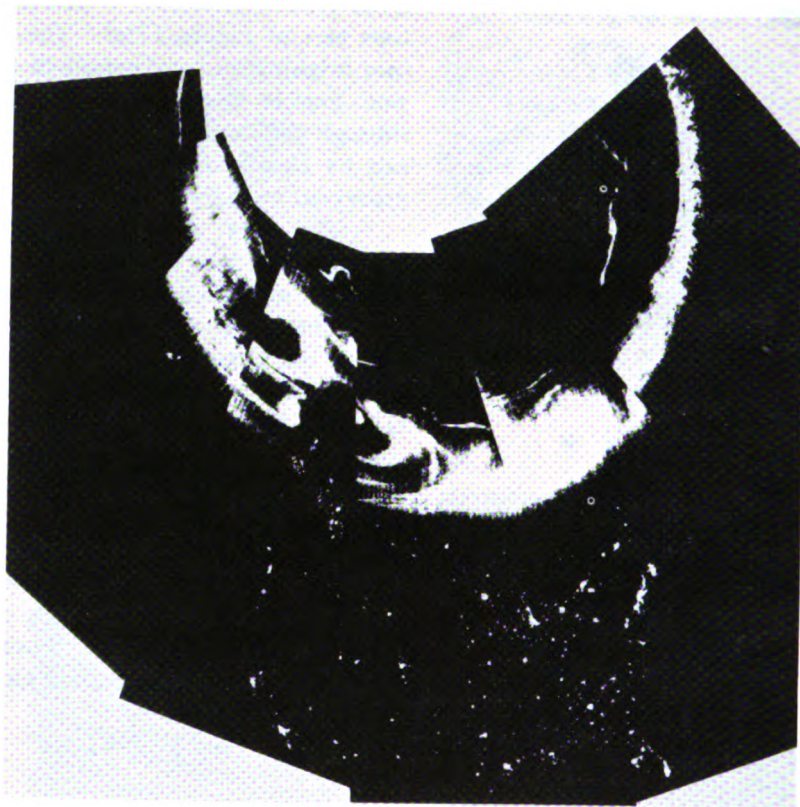
The area of Ne^{+4} emission is roughly coincident with a region of bright x-ray emission, but no emission is detected at the position of the brightest x-ray structure at the northern rim of the Cygnus Loop. The low-temperature lines, such as forbidden O^{+2} ($\lambda 500.7$ nm) and O^{+1} ($\lambda 372.7$ nm), are also weak at the northern rim. The weakness of these lines indicates an absence of gas below 100 000 K, and the absence of Ne^{+4} suggests that only gas above 1 000 000 K is present at this position in significant amounts. In the Veil Nebula, however, all temperature regimes seem to occur simultaneously. Future observations and interpretation will concentrate on understanding these spatial variations.

[Sponsored by ONR]

Coronal Holes During the New Sunspot Cycle, by N. R. Sheeley, Jr., *Space Science Division*

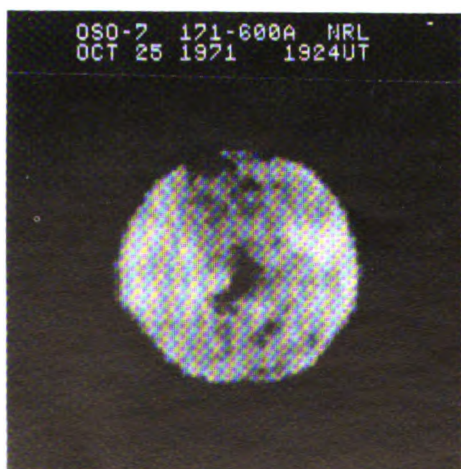
Coronal holes are large, dark, cool voids in the Sun's bright, hot outer atmosphere. Although recently discovered and thus not well understood, these relatively passive solar features actively affect the Earth's magnetic field, because they are the sources of the high-speed streams of plasma in the solar wind. Coronal holes rival and in some ways exceed solar flares in causing geomagnetic and auroral effects.

An NRL program to study coronal holes started in 1971 with extreme ultraviolet (XUV) images that were obtained daily on the 7th Orbiting Solar Observatory (Figure 18). It was extended through the interval from May 1973 to February 1974 with x-ray and XUV images obtained on the Skylab satellite. Since February 1974, infrared solar images have been obtained daily from the ground by the Kitt Peak National Observatory (KPNO) and used to infer the locations of possible x-ray and XUV coronal holes (Figure 19). Most of this study of infrared images has been carried out jointly with J. W. Harvey of KPNO. More



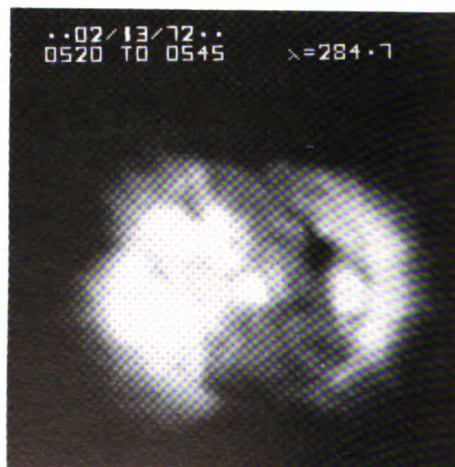
(a)

*(a) Auroral image from the USAF Defense Meteorological Satellite Program
(provided courtesy of E. Rogers of the Aerospace Corp)*



(b)

*(b) Solar image obtained with the NRL
heliograph on OSO-7*



(c)

*(c) XUV spectroheliogram obtained on OSO-7
(provided courtesy of W. Neupert of Goddard
Space Flight Center)*

*Figure 18. Auroral activity over North America (a) and XUV solar images (b and c)
showing the coronal hole that produced it. The coronal hole appears as a dark region
at the disk center in (b) and to the right of the disk center in (c).*

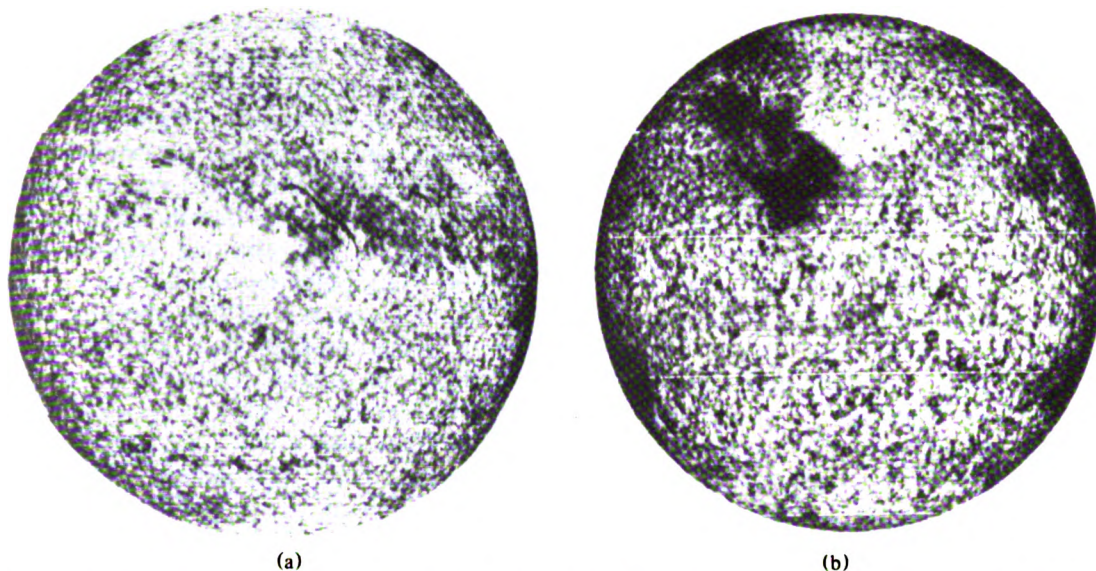


Figure 19. Infrared-wavelength (1083-nm) solar images obtained at the Kitt Peak National Observatory (a) during the declining phase of the old sunspot cycle (Nov. 1975) and (b) during the rising phase of the new cycle (June 1977). The coronal-hole locations can be inferred from lighter-than-average areas (dark areas are active regions) crossing the equator in (a) and north of 35° latitude in (b).

XUV images will be obtained in 1979 when the new SOLWIND NRL satellite experiment (a later version of the NRL heliograph on OSO-7) will obtain solar images routinely.

Studies during 1978 have clarified the nature of coronal holes and their influence on the Earth's magnetic and auroral activity. These studies consisted of an extensive analysis of observations obtained in 1976-1977 when sunspot activity was relatively low and of a preliminary analysis of observations obtained in 1978 as the new-cycle activity began to climb to relatively high levels. A comparison of the new results with our analyses of the 1971-1975 observations is beginning to reveal the way in which coronal holes and their terrestrial influence change during the 11-year sunspot cycle.

The interval 1971 to 1975 marked the declining years of the last sunspot cycle. During this interval, coronal holes were large and long-lived and occurred at low (equatorial) solar latitudes, with their high-speed streams being directed toward the Earth for several days at a time during each 27-day low-latitude solar rotation period. Studies of the Skylab observations indicated that coronal holes were gen-

erated by sunspots and that the holes occurred at low latitudes, because the sunspots occurred at low latitudes at that phase of the sunspot cycle.

In 1976 during sunspot minimum, there were relatively few coronal holes, and most of those were relatively small and short-lived. However, in 1977 as new-cycle sunspots began to appear at relatively high solar latitudes ($\pm 35^\circ$ in each hemisphere), new coronal holes also began to form at these latitudes. Not surprisingly, they shared the slightly longer rotation period of 28 to 29 days characteristic of relatively high solar latitudes rather than the 27-day period of the earlier low-latitude holes. Apparently these new-cycle holes were at such high latitudes that their solar wind streams missed the Earth, because little influence was detected except at the time of year when the Earth was at a relatively high heliographic latitude in the same solar hemisphere as the hole. (The Sun's axis is tilted 7.25° relative to the ecliptic plane, so that the Earth makes an excursion of $\pm 7.25^\circ$ in heliographic latitude during a yearly orbit of the Sun.)

As sunspot activity accelerated in the second half of 1977 and throughout 1978, a

number of sunspot complexes have occurred at lower latitudes and have occasionally generated low-latitude coronal holes. These low-latitude holes of the new sunspot cycle have directed high-speed streams at the Earth, where they have induced geomagnetic and auroral activity.

During 1978, large solar flares associated with the increased sunspot activity have also caused increased geomagnetic activity. Consequently, it has sometimes been difficult to determine whether to attribute a given geomagnetic storm to a coronal hole or a solar flare. Furthermore, in a few rare and interesting cases, neither a flare nor a hole could be identified as the source of the geomagnetic activity. We hope to distinguish these effects during 1979 as the sunspot activity approaches maximum and as the SOLWIND instruments provide new solar observations.

[Sponsored by NASA]

Electron Densities in the Solar Atmosphere, by U. Feldman, G. A. Doschek, and J. T. Mariska, *Space Science Division*

The determination of electron density is critical to the understanding of processes such as heating of the solar corona, propagation of waves through the solar atmosphere, and energy loss in the solar atmosphere. For example, the rate of radiative energy loss is proportional to the square of electron density. Since 1973 NRL has had a program to determine electron densities in the solar atmosphere based on data from the NRL spectrograph on Skylab. This year, calculations were extended into the regime of the solar corona, where temperatures are typically near 1 500 000 K, and the resulting density determinations are among the most accurate to date.

The NRL calculations are based on the intensity ratios of selected pairs of spectral lines in the extreme ultraviolet (EUV) spectral region. These ratios are sensitive to the electron density of the emitting region of the solar atmosphere and provide an estimate of densities independent of the spatial resolution of the spectrograph. Once the density is determined, the volume of the emitting plasma can be found by using other spectral-line ratios. Emitting regions analyzed in this manner are frequently much smaller than can be isolated directly by the spatial resolution of even the best spectrographs. Thus, inhomogeneities in the solar atmosphere which are too small to be observed by direct photography can often be observed indirectly by use of this technique.

The theory of density-sensitive line ratios depends on the fact that certain excited energy levels of ions can be depopulated by electron collisions as well as by spontaneous radiative decay. These levels are the so-called metastable levels, and spectral lines originating from them are called *intersystem* or *forbidden* lines. On the other hand there are *allowed* lines that originate from levels that can be depopulated only by spontaneous radiative decay. Since the effect of electron collisions on the rate of metastable level depopulation depends on the electron density, the ratios of the intensities of forbidden to allowed lines is sensitive to the value of the density. Using atomic theory, the electron density can be calculated from measured line intensity ratios. During 1978, the electron densities were calculated using line intensities for many ions formed in the solar corona.

Figure 20 shows a spectrum recorded by the NRL spectrograph on Skylab for a region

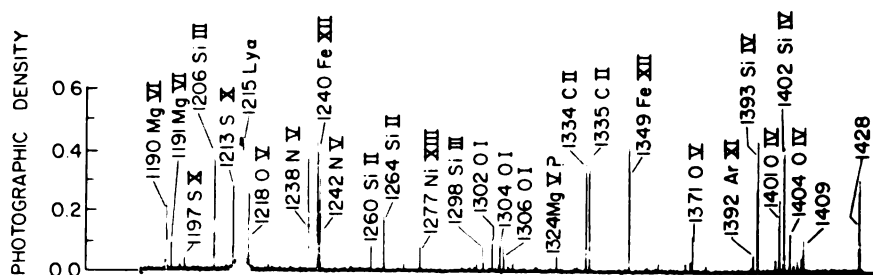


Figure 20. A portion of the solar corona spectrum obtained by the NRL spectrograph on Skylab. (The complete spectrum obtained extended to 200 nm.) The wavelength in angstroms and the ion source of major lines are indicated.

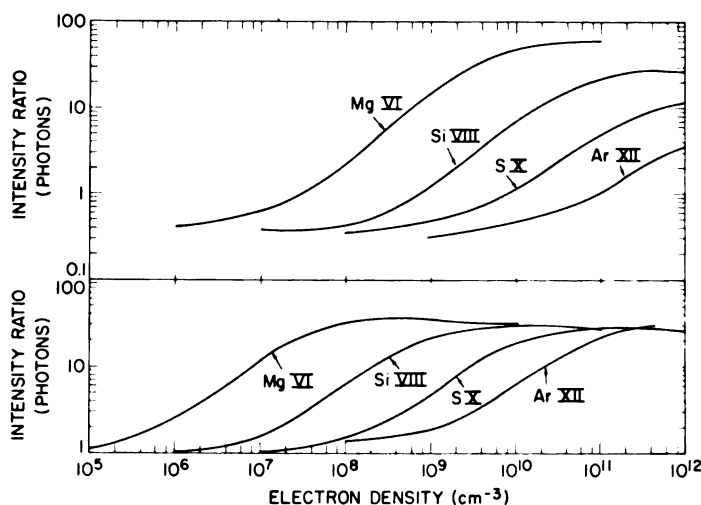


Figure 21. Density-sensitive spectral line ratio useful for EUV diagnostics of plasmas. The top curves give the ratio of the intensities, measured in photons, of the lines that result from the transition ratio denoted spectroscopically as $(^2P_{3/2} \rightarrow ^4S_{3/2}) / (^2D_{3/2} \rightarrow ^4S_{3/2})$. The lower curves give the transition ratio $(^2D_{3/2} \rightarrow ^4S_{3/2}) / (^2D_{5/2} \rightarrow ^4S_{3/2})$.

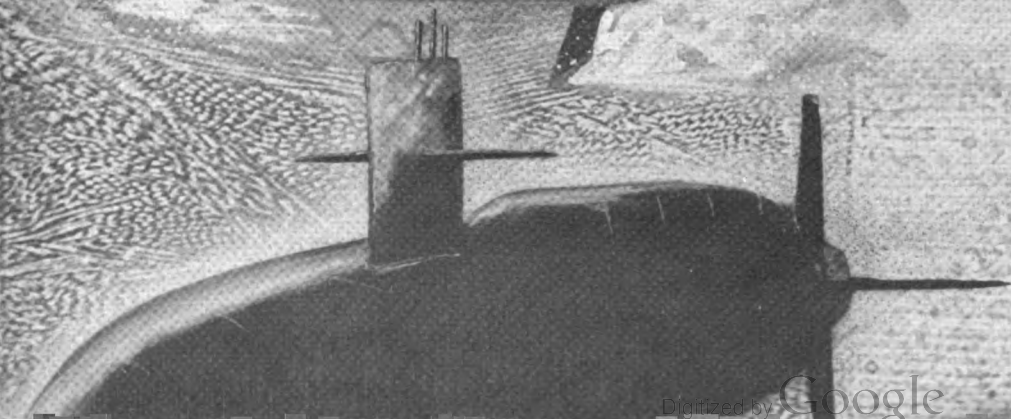
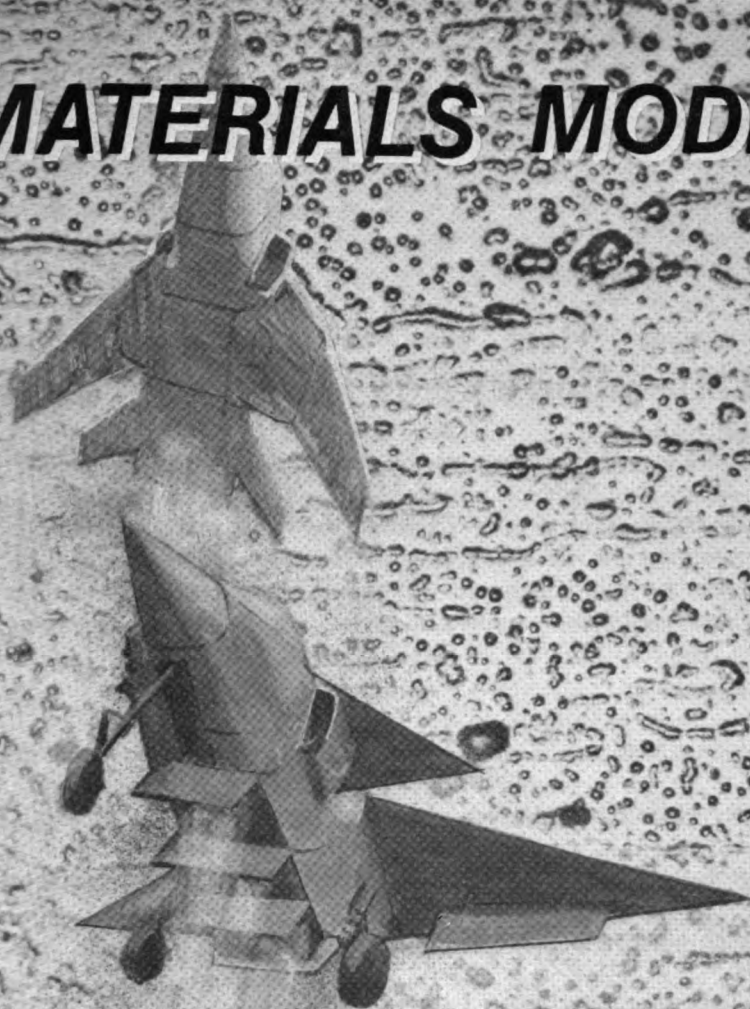
29 000 km above the solar limb. Most of the lines in this spectrum are forbidden lines emitted by the solar corona at temperatures between 5×10^5 K and 3×10^6 K. They are strong relative to the allowed lines of N V (N^{+4}), Si IV (Si^{+3}), and C IV (C^{+3}), which are formed near 10^5 K. In this region, therefore, there is little plasma at this temperature compared to plasma at much higher temperatures.

In regions of the solar corona where the electron densities are low, some of the excited levels of the coronal ions are not effectively depopulated by electron collisions even though they are metastable. Therefore, emissions from these levels behave like allowed lines, and ratios of their intensities to those of other forbidden lines can be used to determine the density.

Figure 21 shows calculated intensity ratios of spectral lines as functions of electron density for a number of ions in the nitrogen isoelectronic sequence (ions with the same number of electrons as nonionized nitrogen). The lines of S X used for the ratio shown in the lower half of the figure appear in Figure 20 at 119.7 and 121.3 nm, and their intensity ratio corresponds to a density of 10^9 electrons per cm^3 . The sizes of the atmospheric regions at this density are much smaller than predicted by symmetric and homogeneous models of the solar corona. Density-sensitive line ratios such as the S X ratio exist throughout the EUV region of the solar spectrum and promise to be a powerful tool for unraveling the mysteries of the solar atmosphere.

[Sponsored by NASA]

MATERIALS MODIFICATION & PROPERTIES



MATERIALS MODIFICATION AND PROPERTIES

The Navy is engaged in a never-ending search for improved capabilities with which to carry out its many mission responsibilities. An all-pervading aspect of the search is the development of new or improved materials that can contribute to enhanced performance. The needs and corresponding opportunities are endless, and NRL programs continue to address many of them through research directed toward new modification techniques and improved understanding of material properties.

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Laser Welding of Thick Sections, by E. A. Metzbow, *Material Science and Technology Division*

Labor is a significant part of the cost of fabricating advanced weapons systems and platforms. Much of this labor is attributed to welding processes. In those systems that require extensive welding, such labor (and associated costs) can be reduced by automating and increasing the speed of welding processes. NRL experimenters, using lasers, have developed automated welding processes that are up to ten times faster than conventional techniques. If adopted, these techniques can result in large-scale savings in labor costs at naval shipyards and other industrial defense facilities.

At NRL, laser welds in thick sections (up to 0.5 in.) of plate have been made in a series of naval materials including quenched and tempered steels, aluminum alloys, and titanium alloys. These single-pass, butt welds were made at rates that varied from 35 in./min for the steels and titanium alloys to 70 in./min for the aluminum alloys. The effective rate for conventional arc welding of these alloys is normally about 1 in./min because approximately eight passes are required to fill in the gap, and each pass is done at about 7 in./min. Thus, laser welding can be done at much higher speeds than conventional arc welding.

Either the pieces to be welded or the laser beam must be moved very rapidly to achieve these speeds. The researchers chose to use a stationary beam and have developed an automatic, numerically controlled process to weld the pieces with the desired speed and precision.

The use of laser welding in more applications requires that the mechanical properties, the fracture toughness, and the microstructure of the fusion zone and the heat-affected zone be determined and correlated to the welding parameters. The researchers found experimentally that laser weldments have mechanical properties that equal or exceed those of the base metal. The laser welds also display a fracture toughness at room temperature that is higher than that of arc welds, even approaching that of the base metal. Because of the thermal treatment experience of the metals, the laser welds display a dramatic increase in hardness that results from a refined solidification structure in the fusion zone (Figure 1). This structure is coarser than the base metal but much finer than that produced by arc welding. Finally, the high energy density of the laser beam and the subsequent high temperature of the melt vaporize the second phase, thereby redistributing and reshaping the inclusions (Figure 2). In summary, the NRL research has determined that



Figure 1. Solidification structure of weld metal along a cross section perpendicular to the plate surface. Note the coarser structure in the fusion zone due to melting and resolidification.

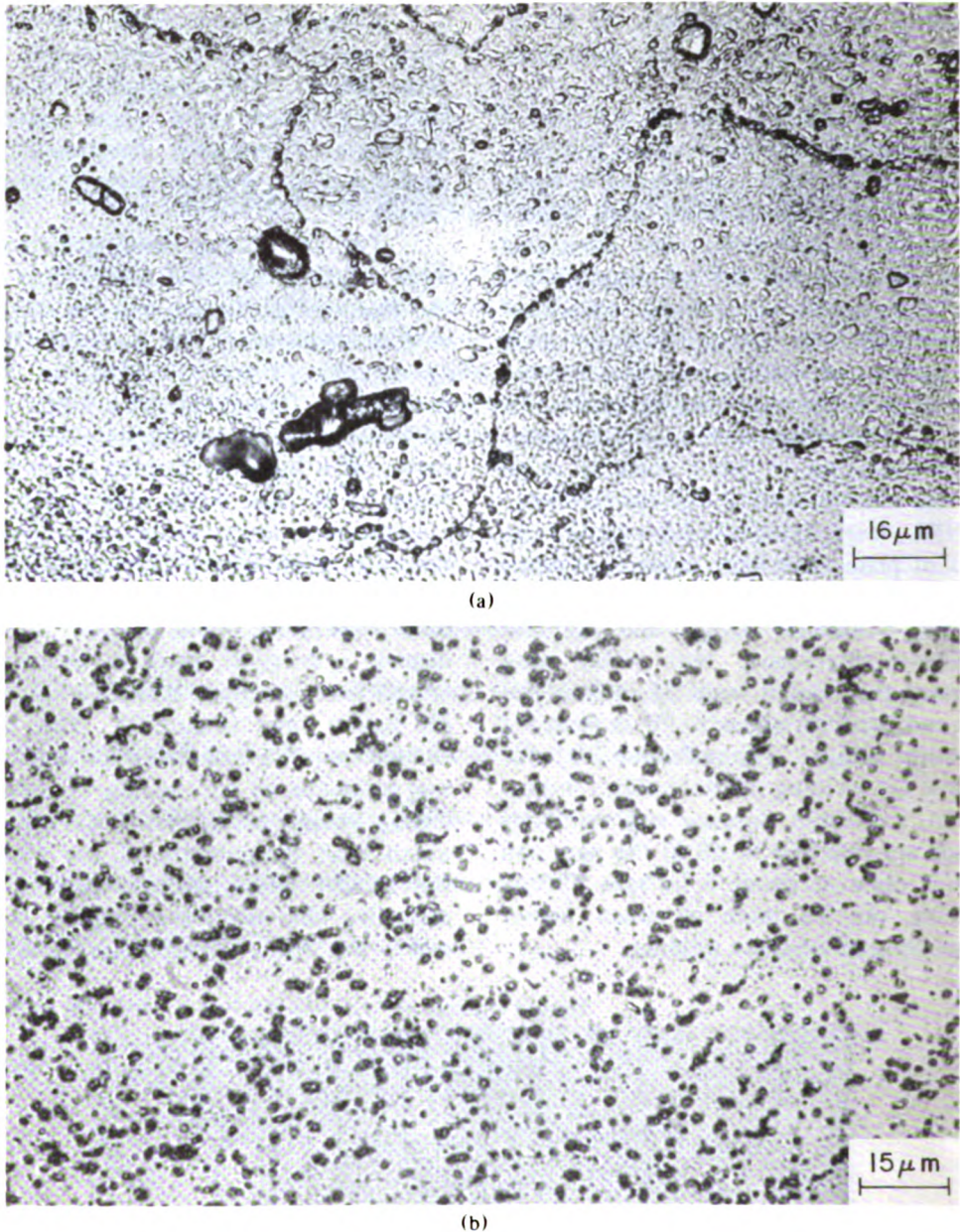


Figure 2. Microstructure of aluminum 5456 alloy (a) base metal and (b) fusion zone of laser weld. Dark spots are beta-aluminum (Mg_2Al_3) precipitates in a matrix of alpha-aluminum. Note the lack of large insoluble particles in the fusion zone after vaporization by the laser beam.

the fine solidification structure and the changes in inclusion shapes and sizes synergistically provide laser welds with properties that are superior to those resulting from conventional arc welds.

A carbon dioxide laser capable of producing more than 15 kW at the joint has been installed for an NRL research program in laser welding of thick sections. Experimental welds in stainless steel have been made in thicknesses

up to 0.5 in. Modifying the joint geometry and using filler metal should produce laser welds in metals with thicknesses up to 1 in. The properties, structures, and welding parameters of these welds will be correlated. Fast welding speeds, good metal properties, and, most significantly, large savings in labor costs are anticipated when this technique is fully incorporated into manufacturing technology.

[Sponsored by ONR]

Surface Hardening of Beryllium by Ion Implantation, by R. A. Kant and J. K. Hirvonen, *Radiation Technology Division*

In recent years, NRL scientists have experimented with the implantation of ions beneath surfaces of various materials to enhance their physical and mechanical properties for a variety of applications. One such material is beryllium, which because of its low density and high rigidity is used as an important metallic constituent of bearings in navigational instruments such as gyroscopes. However, a beryllium surface is too soft to serve as bearing material and must be coated with hard materials such as chromium oxide to inhibit wear. These coatings are difficult and expensive to machine and are prone to adhesion and porosity problems. To solve these problems, scientists at NRL (in collaboration with the C. S. Draper Laboratory at MIT) are investigating the use of ion implantation to harden the surface of beryllium bearings. Their experiments have shown that the hardness of instrument-grade beryllium can be increased significantly by this means.

Ion implantation is a process in which ions, accelerated to high velocities, penetrate materials (e.g., alloys) to produce near-surface regions with properties essentially different from the original material. After implantation, the ions convert to atoms by different mechanisms including charge exchange with the host and chemical bonding.

Ion implantation has several advantages over more conventional methods of changing surface properties. The process can produce a graded alloy from the surface to the unchanged underlying bulk alloy so that both the surface and bulk alloys can be independently optimized. Since ion implantation does not form a coating, porosity and adhesion problems do not arise. Also, implantation causes no macroscopic dimensional changes. Another important advantage of ion implantation *vis-à-vis* conventional surface treatments is that it allows a change in the chemical composition without the limits imposed by thermodynamic factors such as solubility or diffusivity; *i.e.*, ion implantation is essentially a "cold" process. Thus, it creates surface alloy compositions that are difficult or impossible to form by conventional alloying techniques.

Since it can modify virtually any surface property, the technique can be applied to a wide variety of surface-sensitive problems. In fact, NRL scientists have already demonstrated the effectiveness of ion implantation in improving resistance to wear, fatigue, and corrosion. For example, the sliding wear resistance of type-304 stainless steel has been increased 30× to 100× by the implantation of nitrogen.

In the effort to improve the surface hardness of beryllium, boron was implanted because it was expected to form beryllium-boride compounds, some of which are known to be quite hard. The boron was implanted at four different energies to produce a boron-enriched layer 0.3 to 0.8 μm below the beryllium surface (Figure 3). Samples containing 20 at.% and 40 at.% boron layers were annealed at 650°C (1200°F) for 1 h to facilitate the formation of beryllium borides. The microhardness of the implanted samples was measured both before and after the annealing.

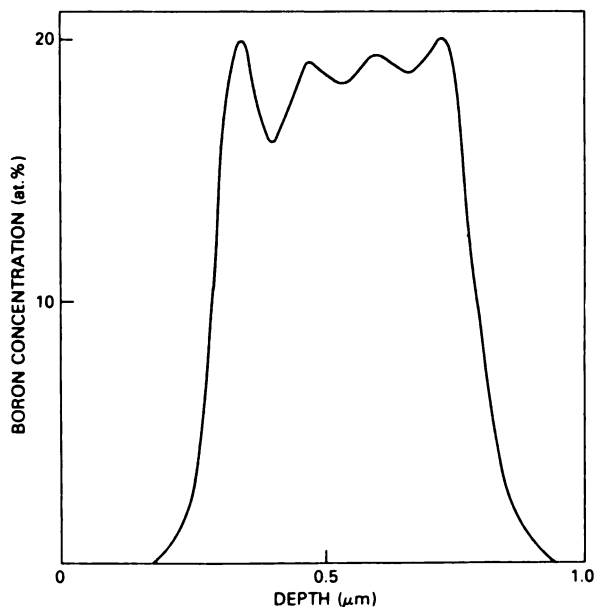


Figure 3. Depth profile of boron concentration in beryllium after implantation at four different energies (95, 140, 190, and 250 keV)

The microhardness measurements were made by impressing a pyramidal (Knoop) diamond stylus into the surface of the sample under a fixed load, measuring the size of the resultant depression, and converting this to a microhardness value related to the the yield

stress of the material. Such measurements are difficult to quantify whenever the thickness of the layer to be measured is less than ten times the penetration depth of the stylus. Nevertheless comparative measurements can serve as useful guides, and the results illustrated in Figure 4 suggest some important conclusions. For example, the ion-implanted material generally is harder than the unimplanted material even without annealing, and microhardness apparently increases with boron dose. The greatest

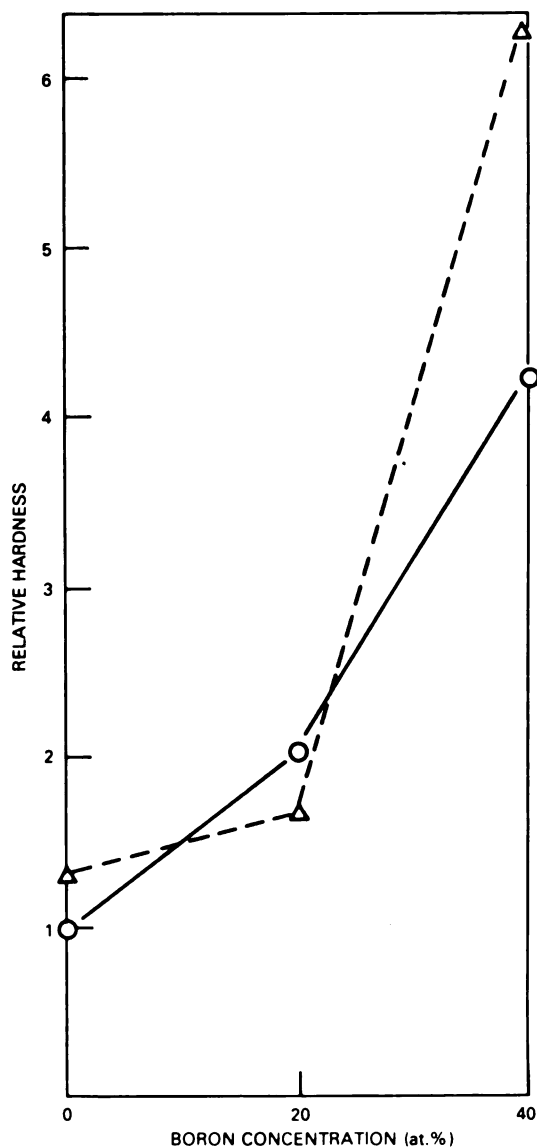


Figure 4. Relative hardness of boron-implanted beryllium alloys before (circles) and after (triangles) annealing at 650°C (1200°F) for 1 h

improvement in hardness occurred in samples that were both implanted and annealed.

The microhardness of near-surface regions can be influenced by several competing factors. Implantation itself increases hardness because of radiation damage and the compressive stress introduced by forcing a large number of impurity atoms into a host lattice. Heating causes a reduction of near-surface damage produced during sample preparation (e.g., polishing) as well as annealing of the implantation-produced radiation damage. Postimplantation heating facilitates the formation of surface oxides or beryllium-boride precipitates to produce precipitation hardening. All of these factors are believed to influence the results shown in Figure 4. However, the most significant hardening was seen for the highest boron-concentration (40 at.%) sample after annealing. This is presumably caused either by the formation of a layer of a hard beryllium compound or the formation of beryllium-boride precipitates, or possibly a combination of both. Future microstructural studies at NRL should reveal which processes are occurring.

Before implanting and testing actual beryllium-bearing components, the researchers will look more deeply into the effects of higher boron doses and dose rates, and different thermal treatments on microhardness. The results will be correlated with those from studies of the changes in microstructure resulting from implantation and annealing. With the insight from these studies, it should be possible to produce beryllium alloys with a microstructure (e.g., distribution of a particular beryllium boride) that will provide the greatest improvement in hardness.

[Sponsored by SSPO]

Carbon Fiber Modification for High Electrical Conductivity, by J. P. Reardon, *Chemistry Division*

Carbon fibers, black filaments of pyrolyzed carbon thinner than human hair but stronger than steel, were first made in the 1950s. Shortly thereafter, they were used as lightweight but strong materials in the construction of vehicles for America's space program. Their most common use is to reinforce plastics (e.g., epoxy) to produce composite materials

for structural applications, especially in recreational products such as casting rods, tennis racquets, golf clubs, and skis. More recently, carbon fiber composites have been used in military aircraft such as the Navy F18 and the Air Force F16, and their use in commercial aircraft and automobiles is expanding greatly.

Carbon fibers are classified by the kind of organic material (precursors) from which they are made and by the temperature of formation into low (1200 to 1600°C), high (1800 to 2500°C), and ultrahigh (2800 to 3100°C) moduli. Only three kinds of the precursors are in use today: viscose rayon, polyacrylonitrile, and mesophase pitch. The preparation begins with slow heating of filaments of precursor material in an oxygen-free atmosphere to drive off hydrogen, oxygen, and nitrogen. This leaves fibers of amorphous carbon in which tiny crystallites of graphitic carbon begin to form as the temperature rises. As graphitization proceeds, the fibers become stiffer and denser, and their ability to conduct electricity increases.

The modulus of a fiber is a measure of its stiffness and is a property of prime importance to structural engineers and designers. The low-modulus fibers have the greatest range of applications, from sports equipment to airplane wings. The more expensive, high-modulus fibers are used for specialty items that require great rigidity, such as mountings for spacecraft optical systems. The ultrahigh modulus fibers are experimental materials and are of interest primarily for their electrical rather than their mechanical properties.

Certain chemical species will react with graphite to form quasi-chemical compounds by intercalation. In this reaction, reagent molecules sandwich themselves between the basal planes of the small graphite crystallites which form during pyrolysis (see Figure 5). Intercalation proceeds in stages which are differentiated by the amount of intercalating species. For example, a small amount of potassium (K) will eventually populate the spaces between every third basal plane of the graphite, forming a third-stage compound, $C_{36}K$. As more K is added, the K atoms distribute themselves between every second graphite layer, forming the second-stage compound, $C_{24}K$. Finally, the

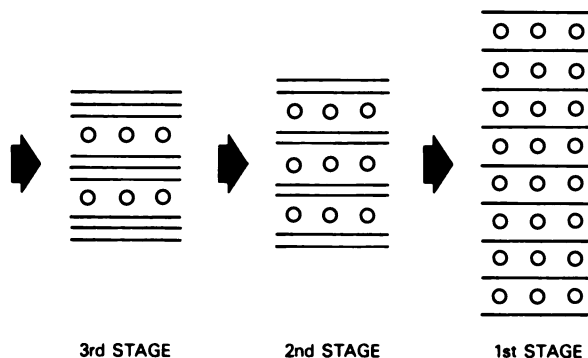


Figure 5. Schematic of the progress of an intercalation reaction. The horizontal lines represent the planes of carbon atoms in the graphite crystallites. The circles represent atoms (or ions or molecules) of the intercalating species, e.g., potassium or ferric chloride.

addition of more K atoms produces the ultimate intercalation with formation of the first-stage compound, C_8K , consisting of alternating K and graphite layers. A variety of elements and compounds other than potassium can be used to prepare intercalated graphites. These include rubidium, cesium, bromine, ferric chloride, and aluminum chloride.

Previously, the main NRL interest in intercalation has been to use the process to modify and optimize certain physical properties of carbon fibers. For instance, a 1976 NRL patent showed how to increase the tensile strength of certain fibers significantly by intercalation with bromine followed by reversal of the process (deintercalation). The fact that intercalation enhances the already good electrical conductivity of carbon fibers has a special appeal because many valuable uses can be easily imagined for highly conductive, lightweight, chemically inert fibers. Such highly conductive fibers promise improved electromagnetic shielding and lightning protection for aircraft with composite construction. They may also provide a suitable substitute for copper in electrical cables in weight-critical situations such as aircraft or submarine applications.

For such uses, however, long-term stability is critical. Unfortunately, most known intercalated graphites are relatively unstable when exposed to the atmosphere for long periods. To circumvent this problem, NRL has been studying the intercalant residues of the fibers.

Generally, intercalants can be removed by heating a fiber in a vacuum, but the process does not always go to completion. A small residue of intercalant remains trapped in the fiber. Some residue compounds of ultrahigh-modulus carbon fibers display relatively large increases in conductivity compared to that of the nonintercalated carbon fibers. For example, the residues of bromine-treated carbon fibers exhibit a fourfold increase and those of iodine chloride treatment show a fivefold increase. Moreover, the residues apparently remain stable despite several months of exposure to the atmosphere.

The conductivity of ICI-treated graphite fiber is about one-twentieth that of copper or about three times that of mercury. NRL chemists have synthesized a group of highly fluorinated, powerful oxidizing agents that show great promise as intercalants that will improve this conductivity substantially. NRL scientists have demonstrated that continuous monitoring of resistance changes in the fibers provides an easy way to identify intercalation stages for the sake of isolating them for further study. In addition, nuclear magnetic resonance techniques have been refined to yield both qualitative (stages and chemical species) and quantitative information about the intercalated fibers.

[Sponsored by ONR and DOE]

Second-Generation Polyphthalocyanines for Structural Composites, by T. M. Keller and J. R. Griffith, *Chemistry Division*

The principal driving force behind the development of composite materials in the Navy is the requirement for lightweight structural materials. The severe weight constraints on carrier-based aircraft in general and on vertical short take-off and landing (V/STOL) aircraft in particular have caused the Navy to look to new design concepts using easily fabricated, fiber-reinforced composites that combine superior stiffness with a high strength-to-weight ratio.

The replacement of the V/STOL's metal structure with fiber-reinforced composites and the use of adhesive bonding techniques could achieve the desired weight reduction. However, conventional epoxy-based composites and adhesives are limited to a 120°C (248°F) maximum service temperature. Other problems

associated with these polymer systems include their brittleness, behavior in the presence of moisture, and engineering reliability. NRL's search for materials having higher temperature capabilities as a replacement for the epoxy matrix resin has led to the development of phthalocyanine resins as candidates for high-performance composite systems.

During fiscal 1978, a new class of diether-linked polyphthalocyanine resins has been synthesized at NRL. These show an improvement in certain properties relative to the NRL diamide-linked polyphthalocyanine resins that are being evaluated as a composite material for the V/STOL aircraft. Two of the new resins show high thermal and oxidative stability (Figure 6), low flammability with high char formation, chemical inertness, and low water absorptivity (Figure 7). Laboratory studies indicate that certain of these resins can provide the desired mechanical and thermal properties at an affordable cost.

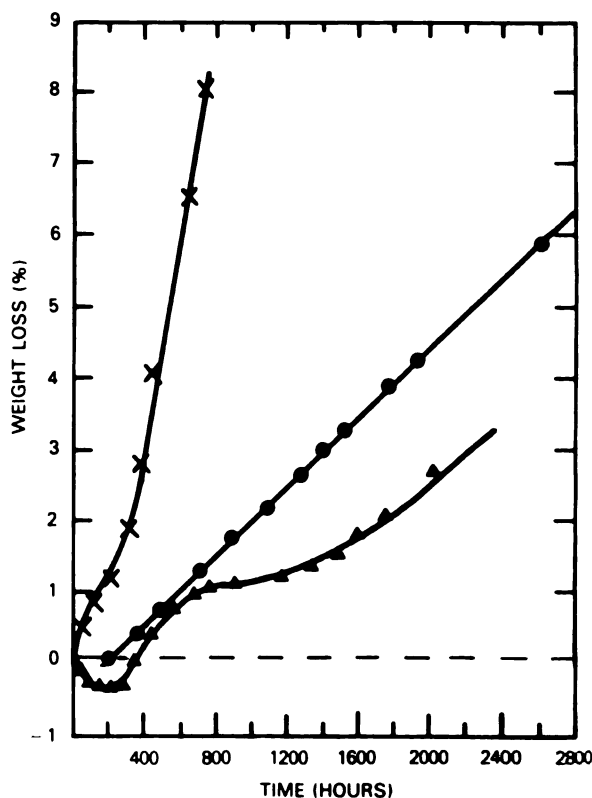


Figure 6. Weight loss of diether-linked polyphthalocyanines at elevated temperatures. Linking unit and temperature: X 1,12-Dodecanediol at 250°C; ● Bisphenol A at 280°C; ▲ Bisphenol S at 280°C. Note that the Bisphenol S initially gains weight, probably due to absorption of oxygen on the surface.

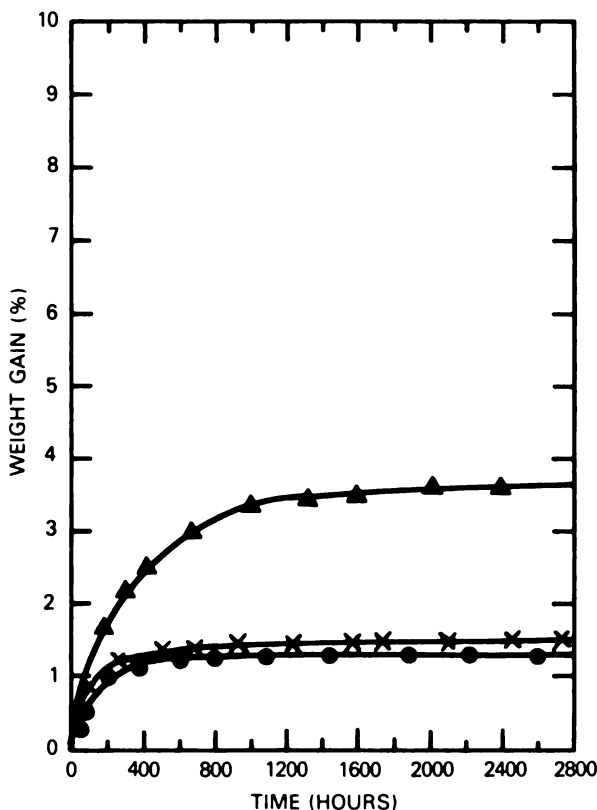


Figure 7. Water absorption of diether-linked polyphthalocyanines on immersion in water at room temperature. Linking units: ▲ Bisphenol S; X 1,12-Dodecanediol; ● Bisphenol A.

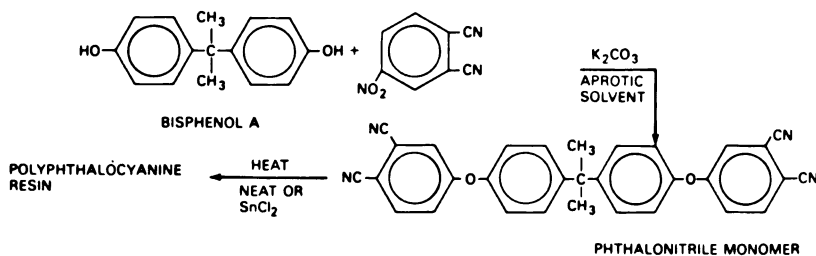


Figure 8. Formation of phthalocyanine resins. Diether-linked phthalonitrile monomers are prepared by simple nucleophilic displacement, activated by cyano (CN), in which the nitro substituent (NO_2) is displaced from 4-nitrophthalonitrile by either an alkoxide or a phenoxide-containing unit.

The phthalocyanine resins are formed by curing the diether-linked phthalonitrile monomers in the presence or absence of metallic salts (Figure 8). The NRL studies are emphasizing highly aromatized, low-cost bisphenol-linked polyphthalocyanine resins. The synthesis of these resins is short and simple and takes advantage of inexpensive starting materials. Thus, in addition to the advantage of new structural variations, the production cost of these resins should compete effectively with

that of other high-temperature polymeric systems.

The bisphenol-linked polyphthalocyanine resins could provide the Navy with new matrix resins for composites. These would have long-term operational capabilities at temperatures greater than 232°C (450°F), be insensitive to high humidity, and have the ability to retain reinforcing fibers during and after exposure to a fire environment.

[Sponsored by ONR]

Plasma-Enhanced Metal Heating with Pulsed Lasers, by J. A. McKay and J. T. Schriempf, *Material Science and Technology Division*

Pulsed carbon-dioxide lasers are capable of very high pulse energies and, in repetitive-pulse operation, of a high average power output. This makes them attractive for metal-working applications now dominated by CW lasers. A possible advantage of pulsed lasers over CW lasers is the generation of plasma-enhanced thermal coupling. Ordinarily, a highly reflective metal such as aluminum absorbs only about 3% of infrared laser irradiation. However, if the laser intensity exceeds a certain threshold level, the air at the target surface will "explode" into an extremely hot, ionized air plasma. NRL measurements have shown that typically 16% of the laser pulse energy appears as heat in an aluminum target when an air plasma is ignited, a fivefold increase over the heat produced by CW lasers.

This gain in thermal coupling occurs because, unlike the metal, the air plasma absorbs nearly all the incident laser power. The plasma then reradiates the power as thermal (blackbody) emission. Because the plasma is extremely hot (close to 20 000 K), this thermal radiation is mainly in the near ultraviolet (UV), where metals have relatively high absorption (typically 50% compared to 3% in the infrared).

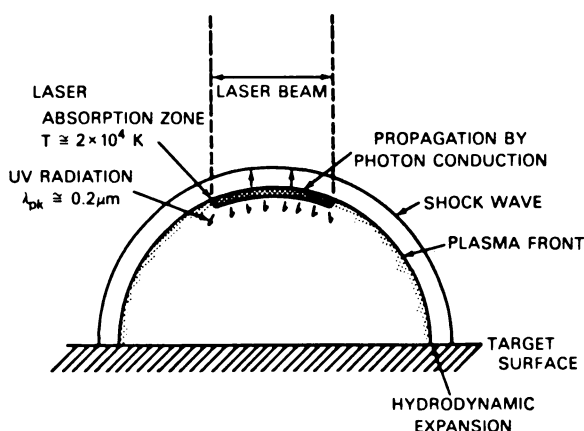


Figure 9. Model of the interaction of laser beam, air plasma, and metal target several microseconds after air-plasma ignition at the metal surface. Beam energy absorbed by the plasma in the laser absorption zone is emitted as ultraviolet (UV) radiation. Upward UV emission heats the cold air and causes the zone to propagate upward by photon thermal conduction. The downward UV emission heats the target with a spatial distribution determined by the plasma-to-target distance.

This reradiated power is distributed with a spatial profile very different from that of the laser beam. It extends well beyond the limits of the laser spot on the target because the hot, UV-emitting plasma zone propagates away from the metal surface at high speed. For metal-working applications, it is important to know the exact spatial distribution of target heating in order to control the target area being heated and to determine the magnitude of heating at the laser spot center. Clearly, if much energy radiates outside the laser beam perimeter, the amount of heat per cm^2 impinging at the beam center is reduced accordingly, so the energy gain of plasma-enhanced coupling is inefficiently used.

NRL scientists have developed a simple model for prediction of the spatial distribution of target heating and have confirmed its validity with measurements using an extremely large pulsed CO_2 laser. The ultraviolet-emitting laser-absorption zone of the plasma is modeled by a disk that has a uniform emission intensity over its surface and moves away from the target surface at constant speed during the laser pulse (Figure 9). The heat deposited at any

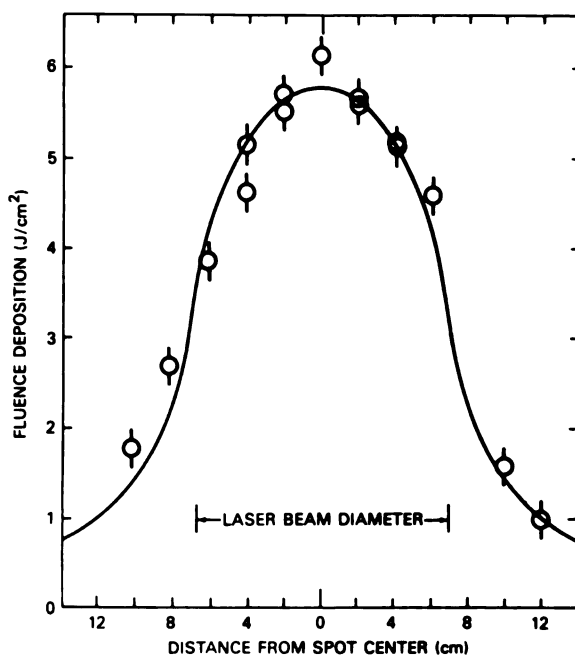


Figure 10. Spatial distribution of the concentration of heat (thermal fluence) in a sheet aluminum target an instant after irradiation by a 10-kJ, 40- μs , CO_2 laser pulse: measured (circles), and predicted by NRL UV thermal-emission model (solid line)

point in the target plane can be calculated by integrating a simple source function over the surface of the disk and over the target-to-disk distance (or time).

The plasma-deposited heat concentration (called thermal fluence deposition) is calculated from temperatures measured with fine-wire thermocouples attached to a thin aluminum sheet. The sheet is backed with heavy Plexiglas® to withstand the force of the air-plasma explosion. Typical results, for a laser pulse of energy 10 kJ, duration 40 μ s, and intensity 2.0 MW/cm², are shown in Figure 10 (circles). The correspondence with the predicted geometry (solid line) based on the simple model is quite good both in the variation in fluence deposition within the laser spot and the falling off of heat outside the spot.

Air-plasma-enhanced thermal coupling may make possible large-scale metal working with lasers of reasonable size. This model can be used to determine the optimum parameters of a pulsed CO₂ laser for high-efficiency, well-controlled metal heat treatment.

[Sponsored by NAVSEASYSOM]

Doping and Impurities in Amorphous Semiconductors, by P. C. Taylor and U. Strom, *Electronics Technology Division*

The versatility of crystalline semiconductors as solid state electron devices depends critically upon the ability to effect dramatic changes in their electrical conduction properties by doping with small amounts of impurities. Such changes occur when impurities incorporated into the host semiconductor cannot satisfy all of their normal bonding requirements so that there are electrons which can be either donated to, or accepted from, the host.

It was commonly thought that, because of the disorder present in amorphous semiconductors, added impurities would be incorporated into the material in ways that would satisfy all of their necessary bonding requirements and that doping would therefore not be effective in these solids. However, recent experiments have demonstrated that, at least in some cases, amorphous semiconductors can be doped. This development has far-reaching consequences for the use of amorphous semiconductors in electronic devices (such as amorphous silicon solar

cells) because these materials are less expensive to produce than their crystalline counterparts, particularly for devices that require large areas.

To understand the details of the doping processes in amorphous semiconductors, NRL scientists have been studying the relationship between added impurities (dopants) and the intrinsic defects in the material. Of great interest at present are the semiconducting chalcogenide glasses which contain at least one of the group VI chalcogen elements (sulfur, selenium, or tellurium). Spectroscopic techniques, such as electron spin resonance (ESR), photoluminescence (PL), and optical absorption, are providing detailed local probes of the intrinsic defects. NRL scientists have determined that those intrinsic defects measured by both the PL and ESR techniques, are holes localized at the chalcogen atoms.

Theoretical models have suggested that it is just these particular defects that provide the electron traps that affect the electrical transport properties of the material, and that doping should dramatically alter the number of these defects. But NRL scientists have recently discovered that many impurities do not change either the number or character of these intrinsic defects, even though the drift mobility for holes, which strongly affects the electrical conductivity of the material, can be varied over several orders of magnitude. Representative ESR and PL data for thallium (Tl) doped into glassy arsenic triselenide (As₂Se₃) are shown in Figure 11. Although the drift mobility changed dramatically over this series of measurements, it is apparent that the numbers of defects measured by these two spectroscopic techniques

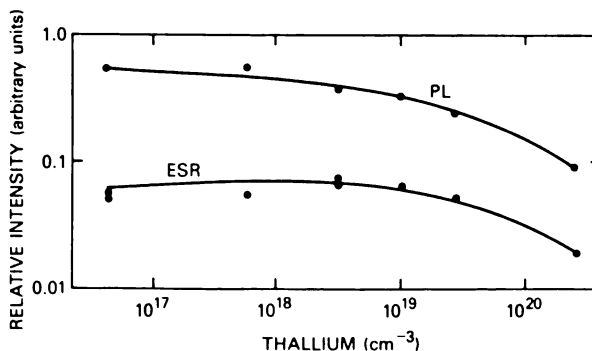


Figure 11. Relative photoluminescence (PL) and electron spin resonance (ESR) intensities observed in glassy As₂Se₃ doped with thallium (Tl) as functions of Tl content

(ESR and PL) did not change appreciably as the thallium content was varied over three orders of magnitude. Only when the thallium content reaches alloy proportions (greater than 10^{20} Tl atoms per cm^3) is there a modest reduction in the ESR and PL intensities. Similar results are observed for all other impurities that have been studied, including alkali metals such as sodium or potassium, transition metals such as iron and copper, and halogens such as chlorine and iodine.

The results demonstrate conclusively that the traps controlling the electronic transport in doped glassy As_2Se_3 are distinct from the defects probed by the ESR and PL techniques. Since existing models hold these defect states responsible for the electrical properties of many amorphous semiconductors, the models must be either modified or abandoned.

Although the gross properties (such as density) of the intrinsic defects studied by ESR and PL techniques in the chalcogenide glasses do not change with the addition of impurities, there are subtle changes (such as the stabilities of the metastable paramagnetic states with temperature) that do reflect the presence of impurity atoms. These less prominent features will be investigated as part of continuing NRL efforts to obtain more detailed information about the role of impurities in determining the defect states in amorphous semiconductors.

[Sponsored by ONR]

High-Pressure Phases of Copper Chloride, by E. F. Skelton, *Material Science and Technology Division*

In 1978, researchers in the U.S.S.R. reported that certain cuprous chloride (CuCl) samples, rapidly cooled at about 500 MPa, undergo a transition from a weak diamagnetic state to one which is nearly perfect. When the pressed samples are cooled at a rate greater than 20 K/min, strong diamagnetic fluctuations are observed at temperatures as high as 170 K; the transition stabilizes at about 100 K. The Soviet scientists interpreted their data as evidence of the Meissner effect, *i.e.*, complete expulsion of magnetic flux from the sample. If present, the effect implies the existence of superconductivity. However, NRL scientists found no evidence of superconductivity in tests

at temperatures from 4.2 to 300 K and at pressures to 10 GPa.

Because of the potential importance of this phenomenon, the multidisciplinary capabilities of NRL were applied to characterize various high-pressure properties of CuCl more accurately. These capabilities include ultrahigh-pressure x-ray, optical, and electronic facilities and Electron Spin Resonance (ESR) and Electron Scanning Chemical Analysis (ESCA) instrumentation that were used by collaborating scientists from three NRL research divisions (Material Science and Technology, Chemistry, and Electronics Technology) and the University of Maryland.

The pressure dependence of the optical transmissivity has been monitored with white light through the anvils of a diamond pressure cell. The series of microphotographs (Figure 12) shows changes in a sample of CuCl as a function of time after pressurization. The sample is subjected to pressures ranging from ambient at the periphery to a maximum of about 10 GPa near the center of the cell. A dark center ring appeared immediately after pressurization, and it was observed that the opacity of the central region grows with time. Approximately 12 h are required to achieve maximum changes as seen in Figure 12(d). Upon release of the pressure, the sample reverted to its original state within 1 h. However, the rate of reversal can be significantly retarded by cryogenic cycling.

In a separate experiment, the relative magnetic susceptibility of CuCl was monitored with an ac mutual-inductance bridge. The growing opacity discussed above was accompanied by a strong change in the relative magnetic susceptibility, and optical stability was accompanied by susceptibility stabilization as evidenced by the relatively small variation of the signal 24 h after pressurization. A similar effect was observed in what are believed to be the first microwave absorption measurements in a diamond-anvil pressure cell. In this experiment, the CuCl -filled pressure cavity was contained in the inductive leg of a microwave resonance circuit. Again, immediately after pressurization, there was a significant and continued increase in the height-to-width ratio (Q) of the resonant frequency curve, accompanied by a shift in the resonance frequency. As the

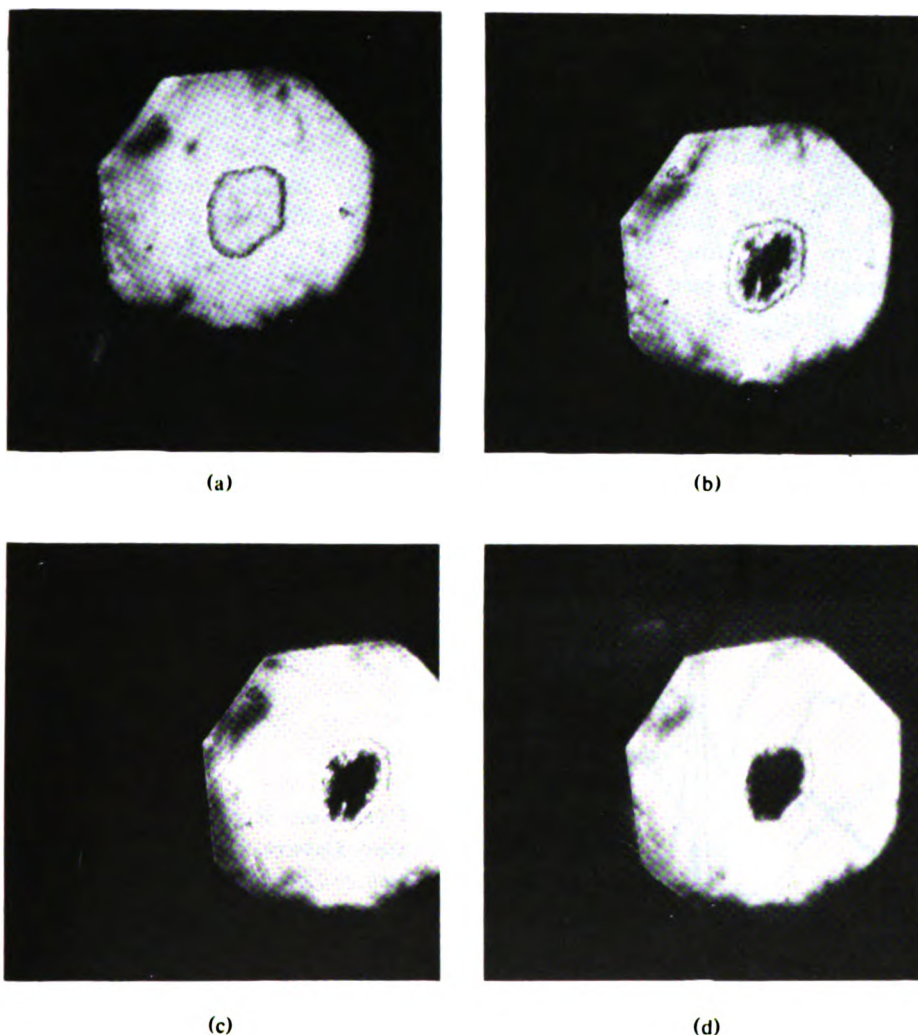


Figure 12. Microphotographs of CuCl pressed between the anvils of an ungasketed diamond-anvil pressure cell. The pressure is estimated to be in excess of 10 GPa near the center and drops off to ambient at the periphery; (a) immediately after pressurization, (b) after 1 h, (c) after 3 h, and (d) after 24 h.

growth of the opaque phase waned, both the Q and the resonance frequency stabilized. All indications are that the CuCl transforms to a more conductive or metal-like phase.

Several theoretical models have been proposed to explain this anomalous diamagnetic susceptibility. Some models invoke a new mechanism for superconductivity, *i.e.*, excitonic electron coupling. According to the accepted Bardeen, Cooper and Schreiffer theory, the electron pairing necessary for superconductivity is achieved through lattice phonons. In the excitonic model, however, this coupling is effected through excitonic states which could produce a material with a much higher T_c . If

CuCl were an excitonic superconductor, it would constitute the first known example. On the other hand, other models suggest that the peculiar behavior of CuCl may be due to a Guinier-Preston transitional precipitate occurring through the disproportionation reaction, $2\text{CuCl} \rightarrow \text{CuCl}_2 + \text{Cu}$, at elevated pressures.

At NRL, a series of experiments was attempted to assess the enhancement of disproportionation by elevated pressures. In one such experiment, ESR measurements were performed *in situ* at elevated pressures. These are believed to be the first of this kind, *i.e.*, high-pressure ESR *in situ*. These ESR data tend to further support the idea of a pressure-induced

disproportionation, confirming earlier ESCA experiments. The microwave absorption curves of CuCl under a fixed load in the diamond-anvil cell are shown in Figure 13 as a function of time after the application of the load. The shoulder identified by the arrow on the uppermost curve at a field of about 3250 gauss is observed to grow with time, along with the increasing opacity discussed earlier. This shoulder can be interpreted as due to the presence of Cu^{2+} .

Another argument in favor of disproportionation is based on a comparison of the

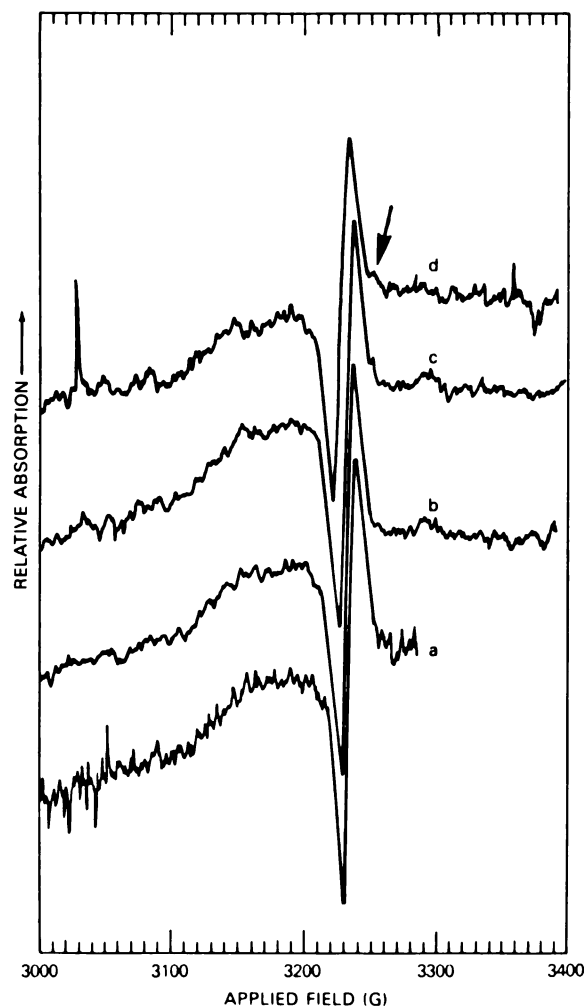


Figure 13. ESR plots for CuCl recorded as a function of time following the application of load. The shoulder at about 3250 gauss, indicated by the arrow on curve (d), can be associated with the presence of Cu^{2+} . Curve (a) was taken immediately after pressurization, curve (b) 1 h later, curve (c), 3 h later, and Curve (d), 24 h later.

compressibilities and the molar volumes of the constituent molecules: Cu, CuCl, and CuCl_2 . Under ambient conditions, the combined molar volume of Cu and CuCl_2 is 1 cm^3 less than that of two moles of CuCl. Moreover, the compressibility measurements for CuCl and CuCl_2 , when combined with published compressibility data for Cu, indicate that the volume reduction associated with the disproportionation reaction is actually enhanced at higher pressures.

These results, when combined with those of other high pressure x-ray and ESCA experiments at NRL, strongly suggest that the unusual properties observed by the Soviet scientists may be due to the disproportionation reaction occurring under nonequilibrium conditions. The NRL measurements indicate that a strong magnetic signature is definitely associated with the optical transition and that a peak in the ESR signal, related to this same transition, could be due to transformation of CuCl into Cu and CuCl_2 .

[Sponsored by ONR]

Cyclotron Resonance in Low-Density Inversion Layers, by R. J. Wagner, *Electronics Technology Division*

One of the most widely used semiconductor devices is the metal-oxide-semiconductor field effect transistor (MOSFET). In addition to its technological applications, however, this device presents unique opportunities for basic studies of electronic transport phenomena. In a MOSFET, charge transport takes place in a thin (10-nm) conducting layer at the oxide-semiconductor interface. This layer can be considered to be almost two-dimensional at low temperatures. By application of a (variable) voltage to a metal gate, the electron density n_s in this layer can be continuously varied. This feature provides insight into the variation of electronic transport processes as a function of electron density.

At low temperatures (1 to 100 K), two types of transport are observed. At high densities ($n_s \geq 5 \times 10^{11} \text{ cm}^{-2}$ for a typical device), the conductivity does not depend strongly on temperature. By analogy, this is referred to as "metallic" conductivity. On the other hand, for $n_s \leq 5 \times 10^{11} \text{ cm}^{-2}$, the conductivity depends exponentially on temperature; this is usually

termed "thermally activated" conductivity. The region of "metallic" behavior is fairly well understood, but the "thermally activated" region presents some rather perplexing properties. A physical model for this region, referred to as Mott-Anderson localization, has received a great deal of attention in recent years. In this model, it is assumed that electrons at low density at the oxide-semiconductor interface encounter a randomly varying potential. This potential is, in general, the result of the random character of the oxide growth process. If the potential fluctuations are large in comparison to the electron thermal energy, the electrons are localized. By heating the device, the electrons are excited into continuum, or current-carrying, states that are separated from the localized states by a characteristic average energy. This model has been used to explain many transport experiments. However, a number of recent measurements suggest that some properties of the oxide-semiconductor interface do not always show Mott-Anderson character. An example of such work is the recent far-infrared cyclotron resonance study performed at the High Magnetic Field Facility by NRL scientists in collaboration with a Bell Telephone Laboratories researcher. This study developed from an earlier experiment on cyclotron resonance at metallic densities in a $\langle 100 \rangle$ Si MOSFET (see NRL's 1974 Review). When a magnetic field is applied perpendicular to the conducting layer, the electrons execute circular motion about the field direction. The frequency of motion is the cyclotron frequency $\omega_c = eB/m^*$, where B is the applied magnetic field and m^* is the electron effective mass. If fixed-frequency laser radiation is transmitted through the MOSFET channel while the magnetic field (thus ω_c) is varied, the condition $\omega_c = \omega_{\text{laser}}$ results in resonant absorption of radiation. The relative width of the line $\Delta B/B_c$, where ΔB is the half-width at half maximum absorption and B_c is the magnetic field at peak absorption intensity, provides a measure of electron collision time. The strength of the line is proportional to the electron concentration.

In the low-density region, transport experiments have shown very short collision times. These results suggest that the cyclotron resonance absorption should broaden and weaken as

density is reduced below $n_s = 5 \times 10^{11} \text{ cm}^{-2}$. This behavior was observed for n_s down to $2 \times 10^{11} \text{ cm}^{-2}$, but at lower densities the absorption line sharpened dramatically. This behavior persisted to the lowest densities studied ($n_s \approx 1 \times 10^{10} \text{ cm}^{-2}$). In addition, near the lowest experimental temperature of 1.5 K, a new absorption line appeared. This line, identified as line L in Figure 14, is the only line present below $n_s \approx 6 \times 10^{10} \text{ cm}^{-2}$. At densities greater than this a new line H grows and becomes dominant as n_s is increased toward $2 \times 10^{11} \text{ cm}^{-2}$.

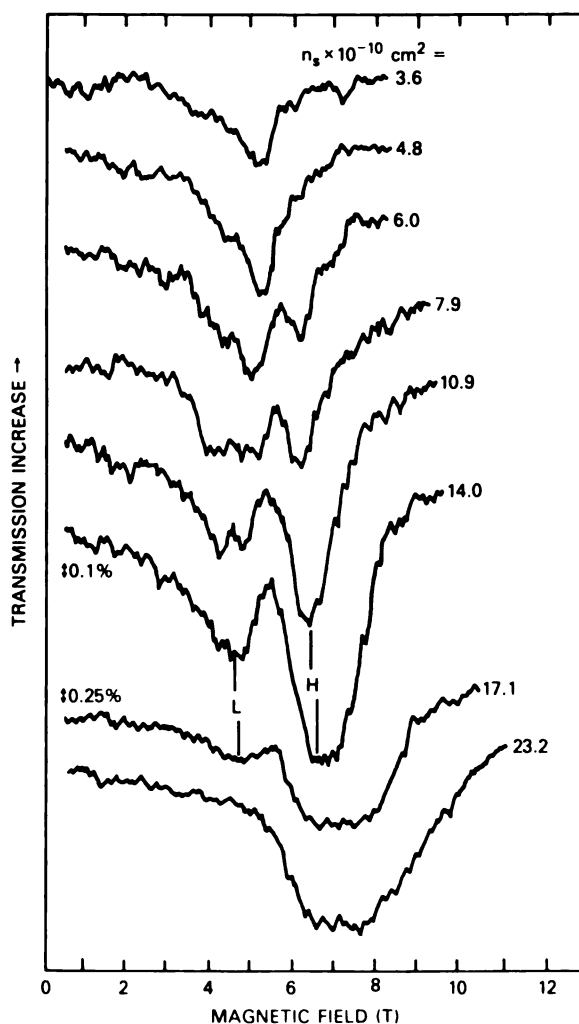


Figure 14. Cyclotron resonance spectra at a number of electron densities for a laser wavelength of $292.5 \mu\text{m}$ and $T = 1.5 \text{ K}$. The curves are displaced vertically to facilitate comparison. The indicated transmission scales of 0.1% and 0.25% apply to the six upper curves and two lower curves, respectively.

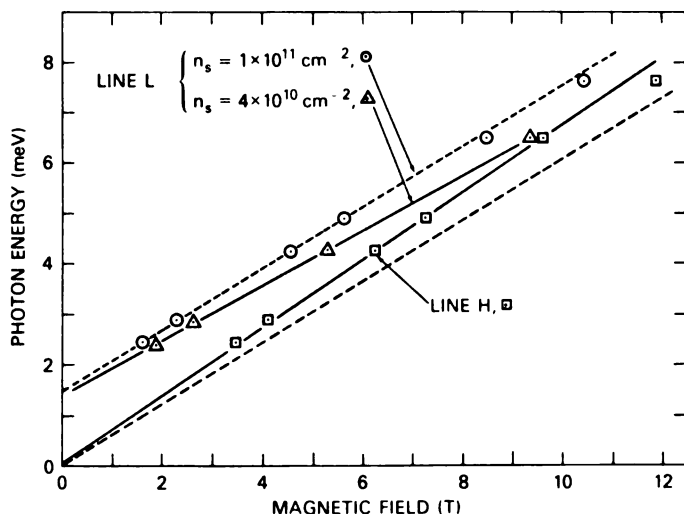


Figure 15. Absorption-line position vs laser photon energy for $T = 1.5$ K. The dashed line through the origin is the anticipated behavior for bulk $\langle 100 \rangle$ Si cyclotron resonance, and the second dashed line has the same slope. Solid lines were drawn as visual aids.

Additional insight into lines L and H can be obtained by repeating the experiment at different laser frequencies. A compilation of these results is shown in Figure 15. Line L is plotted for two different densities, since it has been found to shift slightly with density. The most important feature of this figure is the difference in the behaviors of the two lines. Extrapolation of line H to zero magnetic field gives zero energy, as expected from $\omega_c = eB/m^*$. Extrapolation of line L to zero field, however, yields an energy intercept of 1.5 MeV. A similar behavior has been previously observed in bulk semiconductors, where it has been associated with cyclotron resonance of electrons bound in shallow potential wells. In the present case, it suggests that the first 6×10^{10} electrons per cm^2 introduced into the inversion layer are localized in potential wells with a fairly well-defined energy. This contrasts with the assumption of localization in random potential wells.

The characteristics of line H are less well understood than those of line L. Transport results would indicate that the electrons contributing to this line should be localized, but no evidence for this localization is apparent in Figure 15. Furthermore, the slope of the straight line through the data yields $m^* = 0.17 m_e$, as opposed to $m^* = 0.19 m_e$, which is the effective mass for bulk $\langle 100 \rangle$ Si.

The experiment described above presents an alternate approach to the study of localized electrons in an inversion layer at the oxide-semiconductor interface. The results are not

yet fully understood, but they show promise of giving new insight into the electronic properties of the oxide-semiconductor interface.

[Sponsored by ONR]

Secondary Emission Mechanisms in Oxides, by R. E. Thomas, *Electronics Technology Division*

The secondary emission properties of oxides and other wide band-gap materials are important in many device applications. For example, crossed-field microwave power amplifiers (CFAs), extensively used in radar systems, have secondary emitting cathodes of oxides such as BaO, BeO, MgO, and ThO₂. Although studies indicate that, in metals, secondaries are usually generated by plasmon decay (plasmons are electron density oscillations in the solid), very little is known about the secondary emission mechanisms in oxides. To improve the performance of the devices which depend on secondary emission, one must understand both the mechanisms giving rise to secondary electrons and the changes in material properties which influence these mechanisms. The effort at NRL is directed toward understanding both of these factors.

Various analytical techniques are used to determine the surface properties of the materials being studied (e.g., Auger electron spectroscopy is used to characterize the atomic composition of the samples). To understand the secondary emission processes, however, one of the most important techniques is to analyze the entire energy spectrum of electrons emerging

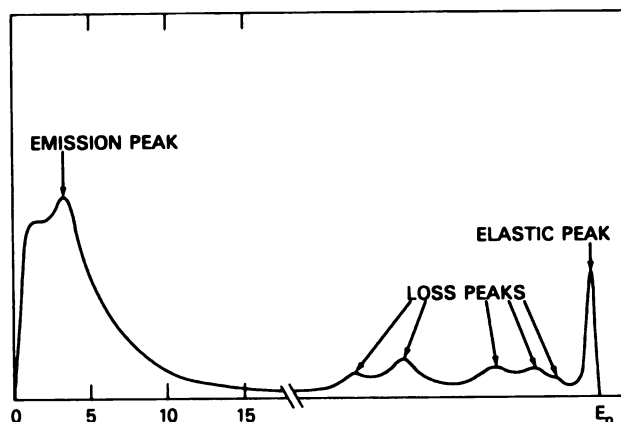


Figure 16. Typical energy spectrum of electrons emitted from oxides

from the sample when it is bombarded by electrons. These emerging electrons are divided into two main groups. One consists of those electrons that are elastically reflected or are reflected with an energy loss caused by exciting some process in the solid, such as plasmons or interband electronic transitions (either of these loss processes can generate secondaries). The second group consists of those electrons within the solid that are sufficiently excited by the incident (primary) electrons that they pass over the potential barrier at the surface and leave the solid. These are called true secondaries, and they generally constitute the largest number of emerging electrons.

Figure 16 illustrates a typical energy distribution of emitted electrons for the materials being studied, where the zero of energy is the minimum energy required for an electron to escape the solid (vacuum level). The large group extending up to about 15 eV contains most of the true secondaries and usually shows one or more peaks (emission peaks) representing an enhanced emission process. The elastically reflected electrons are found in the highest energy peak. Those reflected with an energy loss (loss peaks) occur at somewhat lower energies (the energy lost is the difference between the loss peak and the elastic peak). A careful study of these loss and emission peaks has been made for BaO and correlated with the energies of the bound electrons in BaO (measured by x-ray photoemission spectroscopy). These comparisons indicate that most of the observed loss peaks result from energy lost by the primary

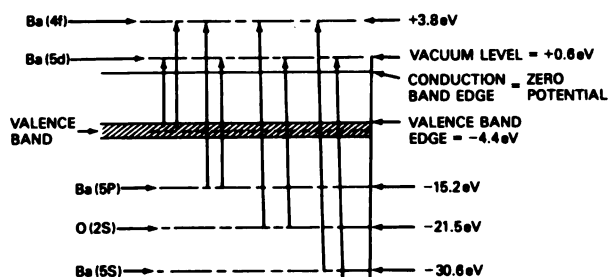


Figure 17. Directly excited electron transitions found for BaO. Electrons are excited by the primary beam from filled states (at the arrow tails) into empty states (at the arrow heads) above the vacuum level.

electrons in directly exciting electrons from the bound states to states at or above the vacuum level. The correlation of the observed transitions with the atomic states involved has provided a self-consistent energy level structure for BaO, as shown in Figure 17. All of these transitions can produce direct secondary emission into vacuum. In fact, it was found that a high density of Ba(4f) states above the vacuum level accounts for a large emission peak found in BaO. Plasmon peaks were also identified in the loss spectrum. However, unlike metals, no emission peaks were found that would correspond to electron ejection by plasmon decay.

Further evidence that secondaries are directly excited from the bound states by the primary electrons was found by measuring the area under the true secondary part of the spectrum as a function of primary beam energy. This revealed that the threshold primary energy

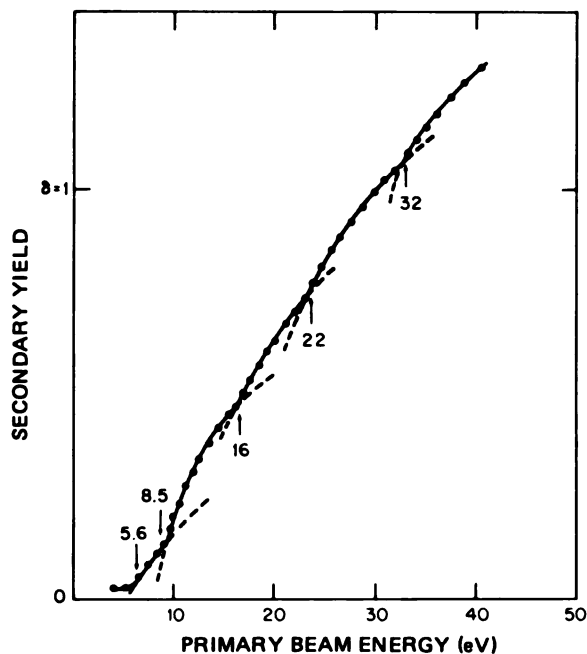


Figure 18. True secondary electron yield for BaO vs primary beam energy. The breaks in the curve indicate the energies at which a new source of secondaries is first excited.

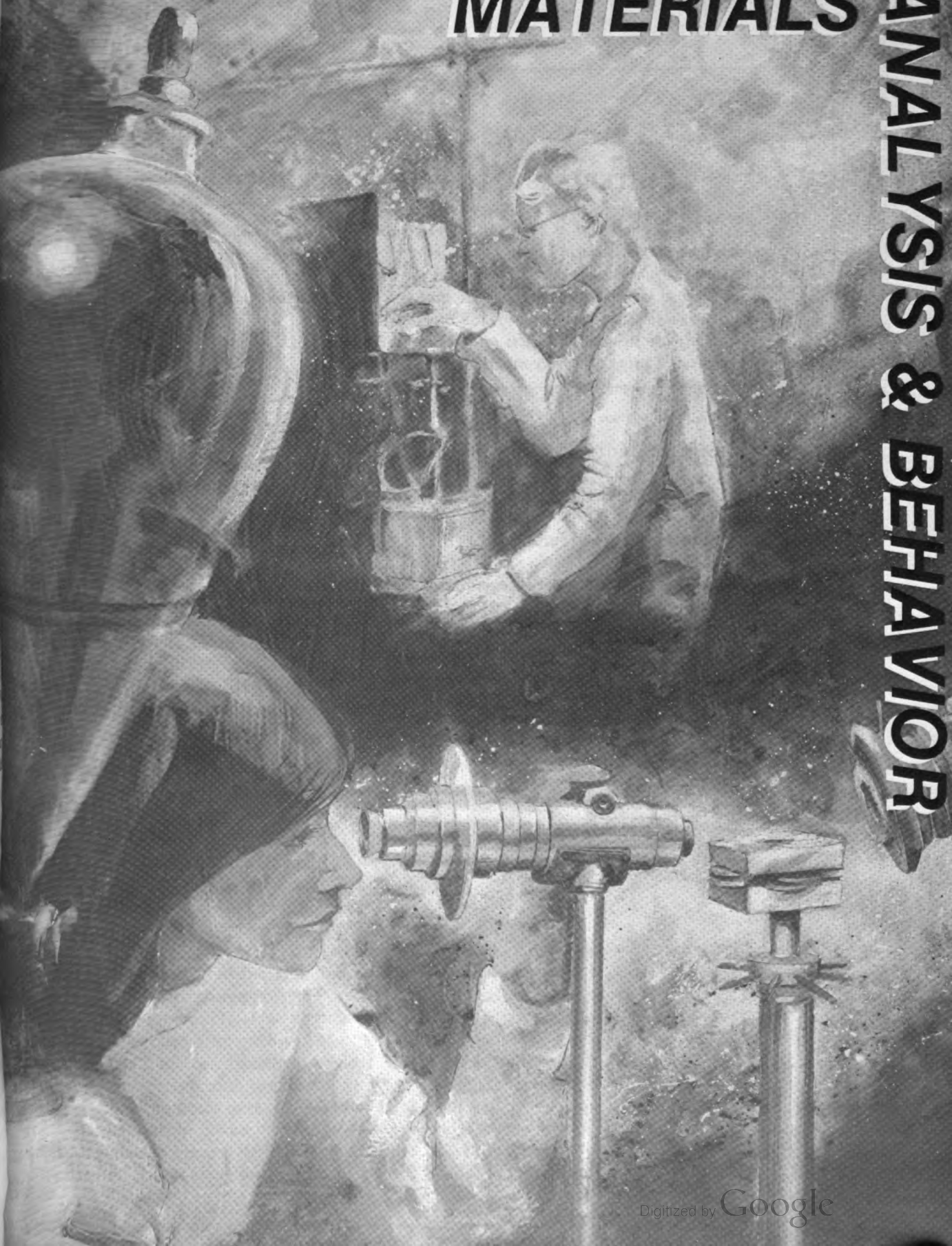
for producing secondaries was 5.6 eV, which is just the energy required to eject an electron from the valence band to the vacuum level. Additional breaks in this yield curve (see Figure 18) correspond to the minimum energies required to eject electrons from deeper bound states.

It is important to distinguish between the direct atomic excitation process such as found for BaO , and other emission processes (e.g., plasmon decay) found in some metals. For example, when trying to modify the secondary

emission properties of a material, the effects of various material modifications, such as adsorbed surface layers and doping effects, will depend critically on which emission mechanisms are important. The results to date have already aided in the interpretation of some CFA degradation processes involving carbon adsorbed on the surface of BeO cathodes. Work is continuing to determine whether the emission mechanisms identified in BaO can be extended to this general class of II-IV oxides.

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MATERIALS ANALYSIS & BEHAVIOR



MATERIALS ANALYSIS AND BEHAVIOR

The development of improved materials and structures to enhance all phases of Navy operations is an important and continuing aspect of NRL research. An intrinsic and essential aspect of these efforts is the ability to identify, measure, and understand those properties and processes that affect or determine the behavior of the materials and their structures. These investigations cover a wide range of topics and frequently are essential adjuncts to other research programs. As such, they typify the strength and value of a truly multidisciplinary laboratory.

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Nondestructive Characterization of Ion-Implanted Silicon, by G. Hubler, P. Malmberg, and C. Carosella, *Radiation Technology Division*

The selective addition of trace impurities (doping) by ion implantation is now widely used in the semiconductor industry as a step in the fabrication of large scale integrated (LSI) circuits. Many techniques, both destructive and nondestructive, have been used to characterize ion-implanted semiconductors, and new methods continue to appear in the literature. A new nondestructive characterization method, developed at NRL (in collaboration with W. Spitzer and C. Waddell of the University of Southern California), employs infrared (IR) reflection measurements to examine the deeply implanted layers produced by high-energy implantation.

This method depends on the periodic intensity variations (interference fringes) that are observed in the reflected IR spectra. These fringes are produced by the interference of light that has been multiply reflected between the samples' front surface and the implanted layer. The large depths (several micrometers) produce many fringe oscillations that provide an enhanced sensitivity to details of the implanted layer. Detailed theoretical analyses of the interference fringe structure can provide refractive index profiles which, suitably interpreted, provide accurate measurements of several quantities of interest.

Figure 1 shows the interference-fringe, IR-reflection data for a (111) silicon sample implanted with 1.5-MeV nitrogen ions to a maximum concentration of 55 at.%. The substrate temperature during implantation was 700°C. The solid curve is the result of a fit to the data (solid circles) of a multiple thin-film interference model in which three parameters were varied: the depth (1.75 μm), standard deviation (0.11 μm), and the amplitude of the assumed Gaussian profile of the refractive index (insert, Figure 1). The obvious agreement demonstrates the ability of the IR reflection method to measure precise, implanted-atom concentration profiles.

At wave numbers less than about 1500 cm^{-1} , the periodicity of the interference fringes breaks down (see Figure 2), indicating that the dispersive effects of the silicon-nitride localized

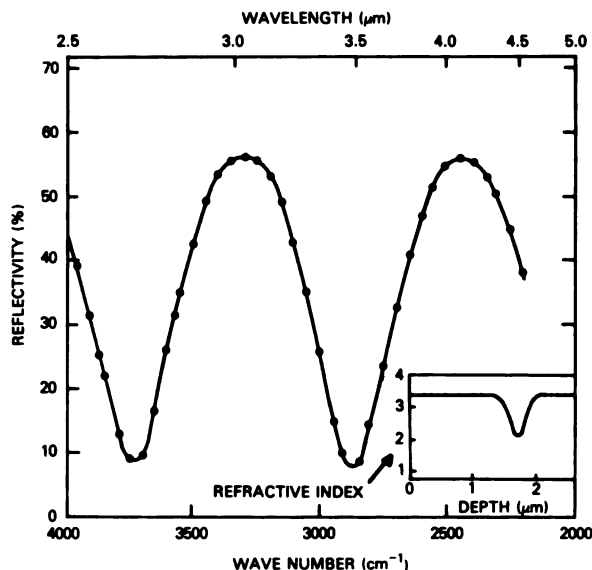


Figure 1. Infrared reflection spectrum for (111) silicon implanted with 1.5-MeV nitrogen ions to a maximum concentration of 55 at.%. The curve represents the calculated fit of a multiple thin-film interference model to the data (dots). The insert shows the inverted Gaussian profile of the index of refraction, used as the fitting function.

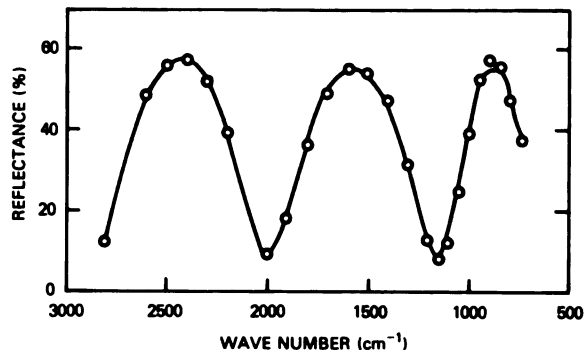


Figure 2. Infrared reflection spectrum (curve) for the same sample as in Figure 1, including the dispersive region $< 1500 \text{ cm}^{-1}$. Calculated values (circles) are based upon classical dispersion theory.

vibrational modes are no longer negligible. The buried layer may be described by computing the optical constants n and k from classical dispersion theory. The buried layer is assumed to be a collection of damped oscillators on the silicon-nitrogen molecules. The results of a calculation that includes two oscillators in the buried layer are shown in Figure 2. Good agreement of the calculated reflection spectrum (circles) with the data (curve) demonstrates that information about the chemical state of

implanted ions may be obtained with this analysis. The oscillator frequencies correspond closely to frequencies present in amorphous and α -phase Si_3N_4 .

The IR reflection spectrum from a (111), highly resistive, silicon sample implanted with 2.7-MeV phosphorus ions to maximum concentration of 0.5 at.% is shown in Figure 3(a). For this fluence, an amorphous silicon cover layer is produced, and the interference fringes are caused by reflection from the amorphous-crystalline transition. The dots are data, and the solid curve is the result of a fit in which three parameters were varied. The parameters and their fitted values are: $R_d = 2.5 \mu\text{m}$, the depth of the amorphous layer; $\sigma_d = 0.035 \mu\text{m}$, the standard deviation of the half-Gaussian used to connect the amorphous refractive index with the crystalline value; and n_d , the refractive index of the amorphous material. A schematic of the refractive index profile is shown in the insert of Figure 3(a) for a frequency of 4000 cm^{-1} . The decrease in interference fringe amplitude with increasing wave number is sensitive to the parameter σ_d , which governs the sharpness of the interface between the amorphous and crystalline layers.

Figure 3(b) presents reflectance data for the same sample after being annealed at 600°C for 5 h. The prominent interference fringes at low frequencies are caused by reflection from the buried conducting layer, which may be treated theoretically as a damped, free-electron plasma. The dispersion relations for a damped plasma were inserted into the multiple thin-film interference model to calculate the preliminary prediction (solid curve) in Figure 3(b). The plasma frequency used in the dispersion relations is proportional to the square root of the free-electron density, which is taken to be a Gaussian distribution. The parameters used for this predicted curve were $R_p = 2.1 \mu\text{m}$ (peak of the Gaussian carrier concentration), $\Delta R_p = 0.22 \mu\text{m}$ (standard deviation), and the carrier concentration at the peak of the Gaussian curve $= 0.7 \times 10^{20}/\text{cm}^3$. A carrier conversion efficiency of 30% is computed from these parameters.

With the methods illustrated in Figure 3, it is possible to study the kinetics of epitaxial regrowth of amorphous layers by performing IR

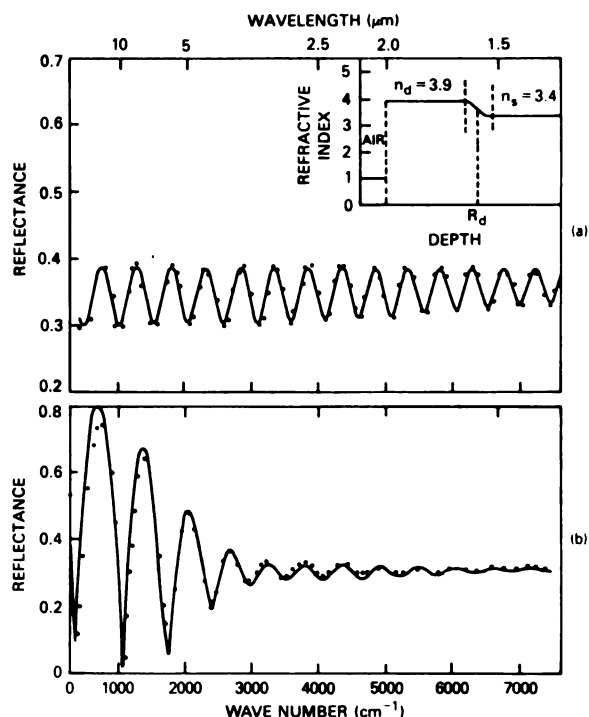


Figure 3. Infrared reflection spectra (dots) for a (111) silicon sample implanted with 2.7-MeV phosphorus ions with a fluence of $1.74 \times 10^{16}/\text{cm}^2$. (a) shows the fit (solid line) using the refractive index profile of the insert as the fitting function; (b) shows the calculated preliminary prediction curve after annealing at 600°C for 5 h (obtained by inserting dispersion relations for a damped plasma into the multiple thin-film interference model).

reflection analysis. The IR method reveals both structural and electrical information by one simple, nondestructive technique. Thus it is complementary to the combined efforts of ion channeling and resistivity profiling. The IR method is being used at NRL to study the regrowth of amorphous silicon as a function of annealing time and crystal orientation.

[Sponsored by NAVMAT and AFML]

Grain-Size Effect on Fatigue of Titanium, by G. R. Yoder, L. A. Cooley, and T. W. Crooker, *Material Science and Technology Division*

Titanium alloys play vital roles in high-performance naval structures where weight, corrosion, or elevated temperatures are important factors. In these applications, the growth of fatigue cracks often limits the useful life of expensive components. Thus the resistance of titanium alloys to fatigue crack growth is an

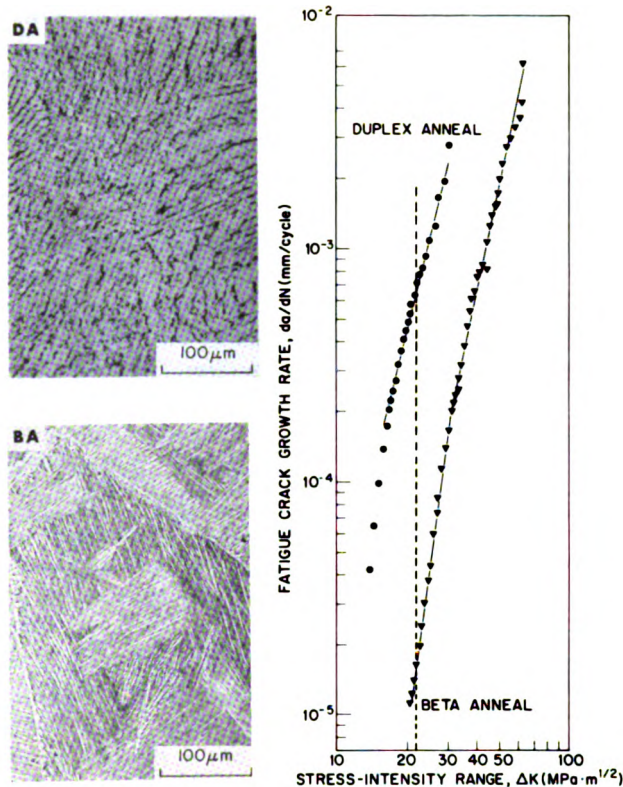


Figure 4. Logarithmic plot of fatigue crack growth rate (da/dN) as a function of crack-tip stress-intensity range ΔK for Ti-8Al-1Mo-1V in two microstructural conditions. The duplex anneal (DA) produces a relatively fine-grained condition, whereas the beta anneal (BA) produces a coarse-grained (Widmanstätten class) microstructure. Note that at $\Delta K = 21 \text{ MPa} \cdot \text{m}^{1/2}$, the fatigue crack growth rate of the BA is about 1/40th that of the DA alloy.

important consideration in determining the service performance of critical naval hardware components and is the subject of ongoing research at NRL.

Studies conducted at NRL over the past few years have shown conclusively that the fatigue crack growth resistance of high-strength titanium alloys can be markedly improved through microstructural modification. An example of this improvement is shown in Figure 4, which shows fatigue crack growth characteristics of Ti-8Al-1Mo-1V alloy in two microstructural conditions as controlled by heat treatment. Modification of the microstructure as shown suppressed the fatigue crack growth rate (da/dN) fortyfold at the indicated stress-intensity range-reference level,

$$\Delta K = 21 \text{ MPa} \cdot \text{m}^{1/2},$$

thus potentially increasing fatigue life significantly. The Ti-8Al-1Mo-1V alloy has been used for naval applications in the duplex-annealed condition, which exhibits the inferior resistance to fatigue crack growth.

Similar trends have been observed in other titanium alloy systems (Ti-6Al-4V, Ti-6Al-6V-2Sn, Ti-6Al-2Cb-1Ta-0.8Mo) during the course of these studies, and the NRL scientists have developed a micromechanistic explanation. In each case, the form of the logarithmic da/dN vs ΔK plot has been found to be bilinear, with a distinct transition point or "knee" in the curve. At this point, loading (defined by the fracture-mechanics fatigue parameter ΔK) reaches a level where the extent of cyclic plasticity at the crack tip equals the effective grain size of the material. This condition is illustrated in Figure 5. The ΔK level at which the

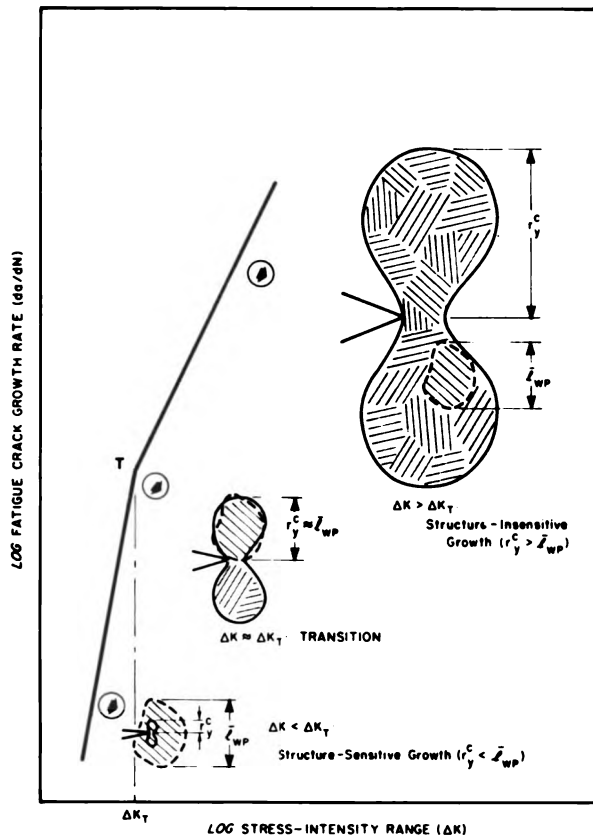
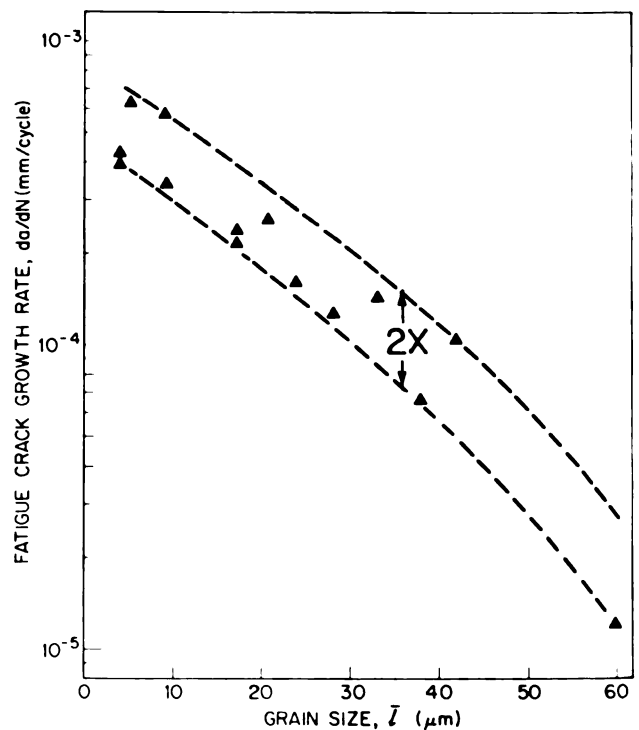


Figure 5. Illustration of the manner in which the relative magnitudes of the cyclic plastic zone (r_y^c) and effective grain size (l_{wp}) influence fatigue crack growth in Widmanstätten titanium alloys. Conditions under which $r_y^c < l_{wp}$ are most beneficial to improving fatigue crack growth resistance.

Figure 6. Relationship between fatigue crack growth rate (da/dN) and effective grain size (l) for a broad sampling of titanium alloys at reference ΔK level of $21 \text{ MPa} \cdot \text{m}^{1/2}$. These data were obtained for a constant set of cyclic loading conditions (load ratio of $R = 0.1$). The narrowness of the data band (bounded by the dashed lines) suggests that there is only a two-fold variation in da/dN for material of a specific grain size.



transition is reached is termed ΔK_T . For $\Delta K < \Delta K_T$, the cyclic plasticity that causes fatigue damage is confined within single grains. This does not keep fatigue crack growth from occurring, but it does cause the crack growth process to be microstructurally sensitive, which is beneficial to fatigue resistance. This microstructurally sensitive crack growth is characterized by extensive crystallographic bifurcation, thus dispersing strain energy and retarding crack growth. For $\Delta K > \Delta K_T$, the scale of cyclic plasticity extends beyond individual grains, and the beneficial effects of microstructural modification can diminish. Overall, the beneficial effects of microstructural modification are most pronounced in the coarse-grained (Widmanstätten class) microstructures that result from the beta-annealing heat treatment or from processing at temperatures above the beta transus for a given alloy.

Success in relating the fatigue crack growth resistance of titanium alloys to a single microstructural parameter (*i.e.*, grain size) represents a significant breakthrough in the area of metallurgical optimization. This relationship is shown in Figure 6, which includes data from a broad sampling of titanium alloys ($\alpha - \beta$ systems) and diverse microstructures. Figure 6 shows that, for a given level of loading, fatigue crack growth rates decrease significantly and systematically as grain size increases. The importance of this unique relationship is that it is the first quantitative link between microstructure and fatigue crack growth resistance in any class of metallic materials. Further studies are under way to assess the significance and generality of these findings.

[Sponsored by ONR and NAVAIRSYS-COM]

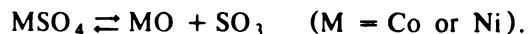
Hot Corrosion of Marine Gas Turbines, by R. L. Jones and S. T. Gadomski, *Chemistry Division*

Gas turbines are being adopted by the U.S. Navy for ship propulsion, with 80 turbine-powered vessels (30 DD-963 class destroyers and 50 FFG-7 class guided missile frigates) soon to be in the fleet. The most critical problem with gas turbines at sea is "hot corrosion"—an accelerated, high-temperature corrosion caused by the reaction of sea salt with

the hot turbine blades. Hot corrosion was believed to require a *molten* sodium sulfate (Na_2SO_4) film on the blade surface, and thus was predicted to be potentially troublesome only at high-power operation of the engine where the blade temperatures exceed the Na_2SO_4 melting point (884°C). Unexpectedly, however, severe hot corrosion of blades was discovered to have occurred at only 650° to 750°C during low-power tests of the Navy ship propulsion engine (LM-2500). This discovery caused serious concern because the LM-2500 engine will operate most of the time at low or intermediate power levels.

Blades of the LM-2500 are protected by a thin coating of CoCrAlY, an alloy of cobalt, chromium, aluminum, and yttrium developed specifically to resist hot corrosion. This coating was quite effective in high-power (900^+°C blade temperatures) engine tests which ran as long as 7000 h. In low-power operation, however, characteristic pitting (Figure 7) routinely penetrated the CoCrAlY in less than 3000 h (within 500 h in one sea test).

A NAVSEA-NRL Hot Corrosion Task involving cooperative industry-NRL research was established to solve the hot corrosion problem. This Task was the first to reveal the second region of hot-corrosion susceptibility at 650° to 750°C , heretofore unrecognized by the gas turbine industry. This lower temperature hot corrosion is caused by formation of low-melting mixed sulfates from the cobalt sulfate-sodium sulfate (eutectic at 575°C) and nickel sulfate-sodium sulfate (eutectic at 670°C) systems. Cobalt and nickel sulfate are thermally unstable and undergo a reversible decomposition to the respective metal oxide and SO_3 at elevated temperatures:



However, at 650° to 750°C , the equilibrium partial pressure of SO_3 is low, and as little as 10 to 100 Pa of SO_3 is enough to reverse the reaction. These levels of SO_3 are readily attainable by oxidation of the up to 1% sulfur allowed (for economic reasons) in Navy fuel. Therefore, cobalt and nickel sulfate are formed by reaction of the oxides normally occurring on the blade surface with SO_3 in the engine gas. These sulfates interact with Na_2SO_4 from the sea salt to

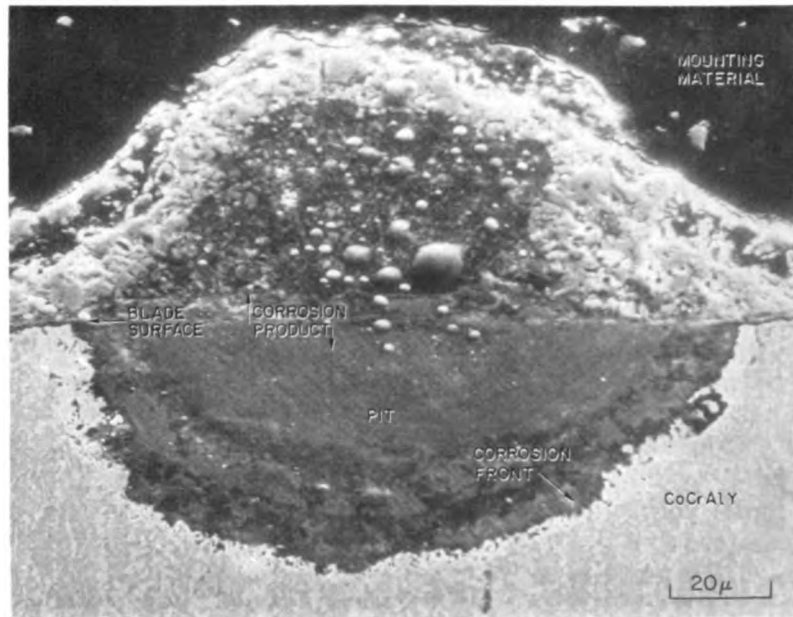


Figure 7. Photomicrograph of a cross section of low-temperature (760°C) hot-corrosion pit on a CoCrAlY-coated blade specimen. Line through the center of the pit represents the original blade surface. Notice the "clean" corrosion front and equal attack on both CoCrAlY phases which are believed to result from the acidic nature of low-temperature hot corrosion.

produce a mixed sulfate film, which is both molten and, because of the metastability of the metal sulfate, acidic (rich in SO_3). The combination causes severe corrosion, normally in the form of a characteristic pitting.

NRL research has been fundamental in elucidating the low-temperature corrosion mechanism. In the early stages of the problem, NRL experiments showed that the decomposition of mixed sulfate deposits produced corrosion identical to that seen in low-power engine tests. Later NRL work demonstrated that the mixed sulfates are produced from the metal oxides and Na_2SO_4 under the very low SO_3 pressures indicated, and that the total process of eutectic sulfate formation and corrosion could in fact be duplicated in the laboratory.

The clear identification of the existence and mechanisms of low-temperature hot corrosion, including the critical role of SO_3 and the susceptibility of cobalt-based and, to a lesser extent, nickel-based alloys, has provided the basis for NAVSEA to initiate the development of improved coatings and blade alloys to protect

the fleet's turbines against both low- and high-temperature hot corrosion.

[Sponsored by NAVSEASYSKOM]

Fatigue System for Environmental Effects Studies of Reactor Steels, by H. E. Watson, *Material Science and Technology Division*

Conservative criteria based on fatigue-crack growth-rate data are needed to assure the safety of operating nuclear systems. Since flaws are known to exist in thick sections of steel, it is necessary to obtain a relationship between flaw size and operating conditions to guard against failure. Flaws in the presence of high stress concentrations will become propagating cracks. The current objective of this program is to establish the relationship between flawed materials and operating conditions. Acquisition of the necessary data requires highly specialized equipment.

One example of such equipment is the environmental fatigue crack-growth system (Figure 8) that simulates the operating conditions (except radiation) of power reactors. This

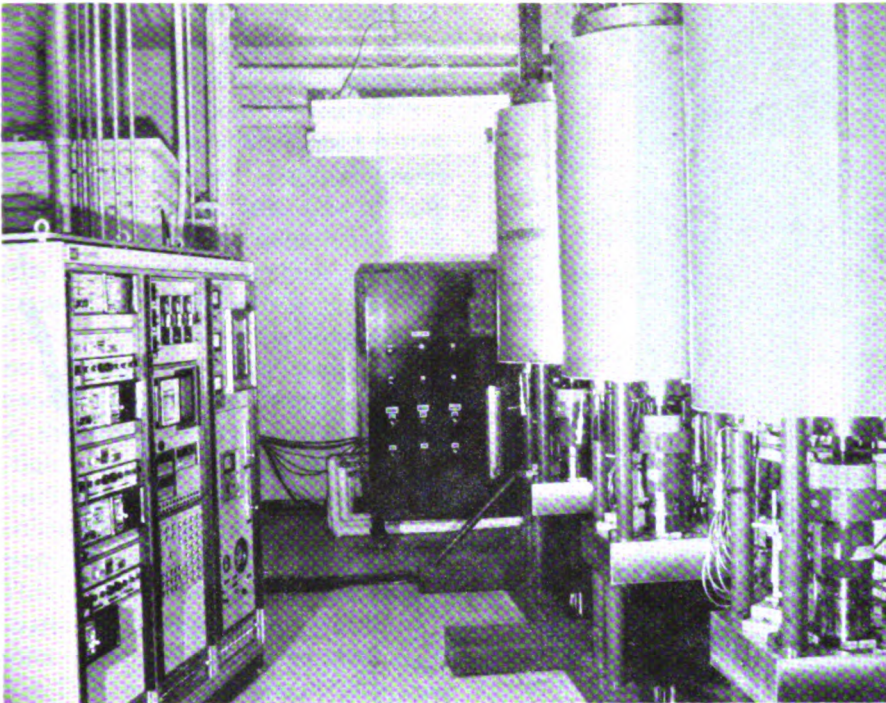


Figure 8. NRL's new environmental fatigue test system showing the three autoclaves (at right), the control console (at left), and the water handling system (in the background)

prototype test system was designed by NRL engineers and consists of three test chambers (autoclaves), a water conditioning and pressurization system, and a control console. The system can test up to four 2-in. or two 4-in. thick specimens in each of the three autoclaves. During operation, the autoclaves are filled with reactor grade water, pressurized to 14.7 MPa (2000 psi) and heated to 288°C (550°F). In this condition, the force against the autoclave head(s) exceeds a million pounds. Once the environment has been established, it is necessary to apply loading waveforms (sine, ramp, hold, *etc.*) that simulate as closely as possible the events that occur in service. Each autoclave is independently controlled, so that up to three different loading waveforms can be evaluated simultaneously. The data required include the crack length from each specimen, the water temperature at each specimen location, the pressure inside the autoclave, the load applied to the specimens, and the cycle count. With four specimens in each autoclave, this means 33 different bits of data for the system. In addition, the bulk water pH, oxygen, and conductivity are continuously monitored and

recorded for each data point. A single crack-length determination requires 100 sample points and each point is recorded three times and then averaged to reduce scatter.

A system of this complexity requires an automated data acquisition and reduction system to function properly. A Hewlett-Packard System 45 desk-top computer satisfies this requirement. The system features a measurement and control processor as the data acquisition peripheral and a floppy disk drive for program and data storage. The reduced data are recorded continuously. They are then stored for retrieval upon command and for plotting as needed to show the status of the tests in progress.

Some fatigue crack-growth tests involve very low cycling rates and may take 2 years or more to complete. The design of this system permits the use of several specimens of the same material to generate a single set of data, thereby reducing the testing time by a factor of 3 or more. This is accomplished by using three or more specimens linked together (see Figure 9), each with progressively longer initial crack lengths. Safety links are provided to limit the

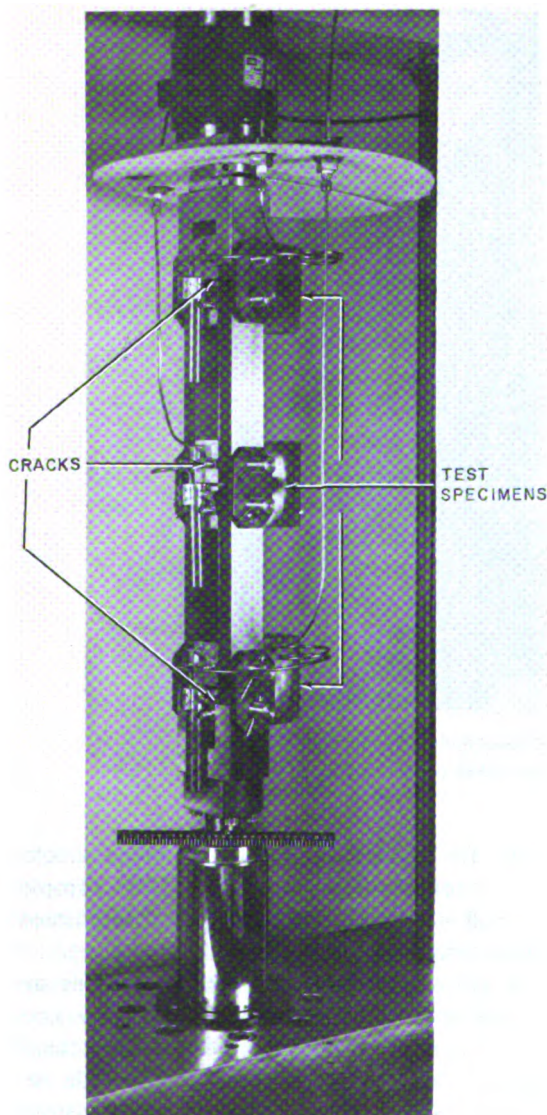


Figure 9. Three specimens are shown mechanically linked together before being loaded in one of the multispecimen auto-claves shown in Figure 8. The cylinders attached to each specimen monitor fatigue crack extension during the test.

amount of crack extension and to prevent the failure of a specimen before the test objective is reached. Data from a test of this type are shown in Figure 10. Another advantage of this multispecimen approach is that trends can be established very early in the test from specimens with the longest crack, whereas the single specimen approach may take several months before data are obtained.

This test system, the most advanced of its type in use, has enabled NRL to assume a leadership role in studies of the environmental

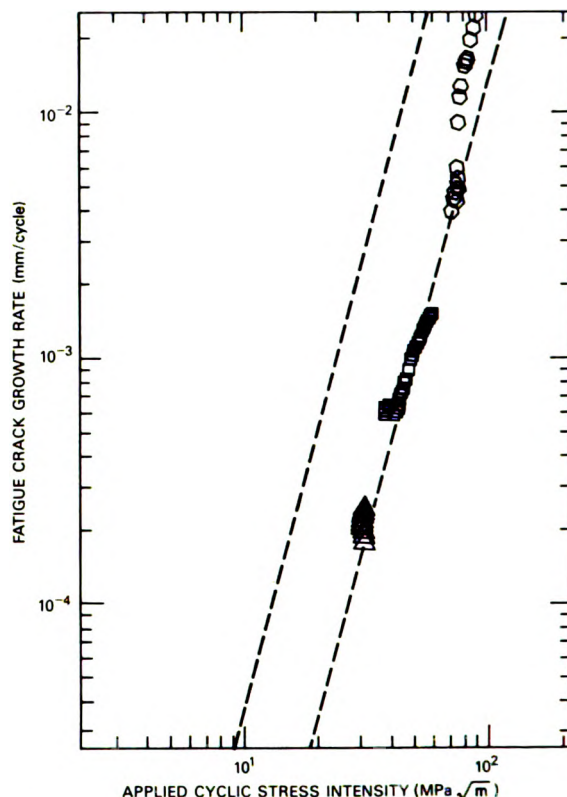


Figure 10. Fatigue crack-growth-rate data obtained from three specimens with three different initial crack lengths. Dashed lines are upper limits for reactor steels in air and water environments established by the American Society of Mechanical Engineers (ASME). Data are generated early from the specimen with the longest crack. Initial data from the shortest crack (Δ) are obtained only after several months of stress.

fatigue crack-growth rate. Experience in the use of this system led the NRL engineers and designers to suggest to sponsors the establishment of an international cooperative so that each participating nation could benefit from the cumulative research. Eight nations now participate in this venture, which has been formally named the International Cooperative Group on Cyclic Crack-Growth Rate Studies.

[Sponsored by Nuclear Regulatory Commission]

An Exact Method for Guyed Tower Analysis,
by F. Rosenthal and R. A. Skop, *Ocean Technology Division*

The increasing requirements for military and commercial operations in deeper offshore waters (>300 m) have necessitated a new generation of offshore structures. As compared to

the classical platforms, these new structures, such as guyed towers and single point moorings, tend to be quite flexible in their responses to ocean forces and thus difficult to analyze.

Scientists at NRL have developed a new method for the static analysis of guyed towers which incorporates the exact solutions of both the nonlinear tower and guy equations. The effects of axial forces, as well as shear deformations in the tower, are taken into account. The tower and the guy cables may be subjected to any given set of forces such as those produced by gravitational, current, and wind loadings. The base of the tower, which is inserted into the ocean floor, may be supported with any degree of stiffness between clamped (tower remains vertical at bottom end) and hinged (zero moment at bottom) including either extreme. This latter feature allows the incorporation of various sediment characterizations.

The solution process is an iterative one, as indicated in Figure 11. As noted above, calculations of the guy and tower configurations within the iteration proceed *via* exact numerical solutions of their governing differential equations. The initial estimate of the tower configuration is usually taken as its geometry under zero load. The tensions and angles of the guys, and their effective spring constants acting on the tower, are calculated using procedures developed earlier at NRL. These cable forces and spring constants are then used, together with the tower nonlinear beam column equations, to determine a corrected tower configuration, and the whole process is repeated until desired convergence criteria are met.

Results of a calculation for a sample two-dimensional problem are shown in Figure 12. A platform weighing 34×10^6 kg and subjected to a 1.11×10^6 N wind load is supported by a 458-m high beam column tower whose weight per unit length is 297 kg/m. The tower has a bending stiffness of 3.52×10^{13} Nm², a compression stiffness of 1.51×10^{11} N, and a shear stiffness of 4.45×10^{10} N. The tower is assumed to be hinged at the bottom and is subjected to drag forces, parallel to the wind, of 627 N/m of length, corresponding to a current 0.5 m/s.

The tower is supported by two 18-cm diameter cables, one on each side. Each cable weighs 74.3 kg/m, has an unstressed length of

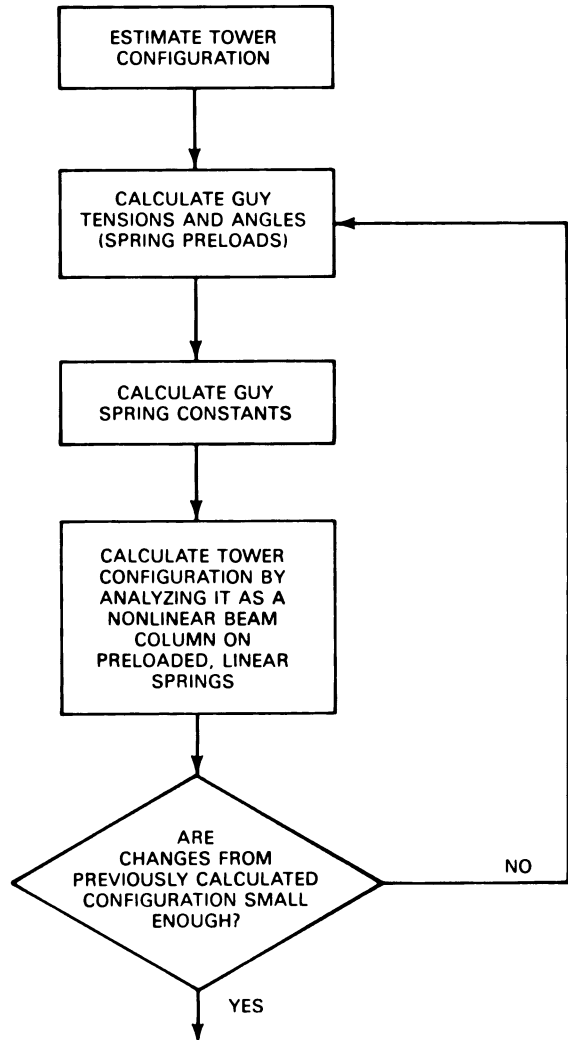


Figure 11. Flow chart for guyed tower calculation

930 m (which leaves 15 m slack), a tensile stiffness of 1.78×10^9 N, and is subjected to a drag force of 29 N/m. The cables are anchored at points 793 m from the base of the tower.

Figure 12 depicts the displaced configuration of the tower and cables, and shows the calculated bending moment in the tower reaching a maximum 29.6×10^6 Nm near the center of the tower. These bending moments are relatively modest, being due entirely to the presence of the flow drag forces, since the end forces on the tower are below the Euler buckling load.

Progress to date includes completion of a small two-dimensional demonstration computer

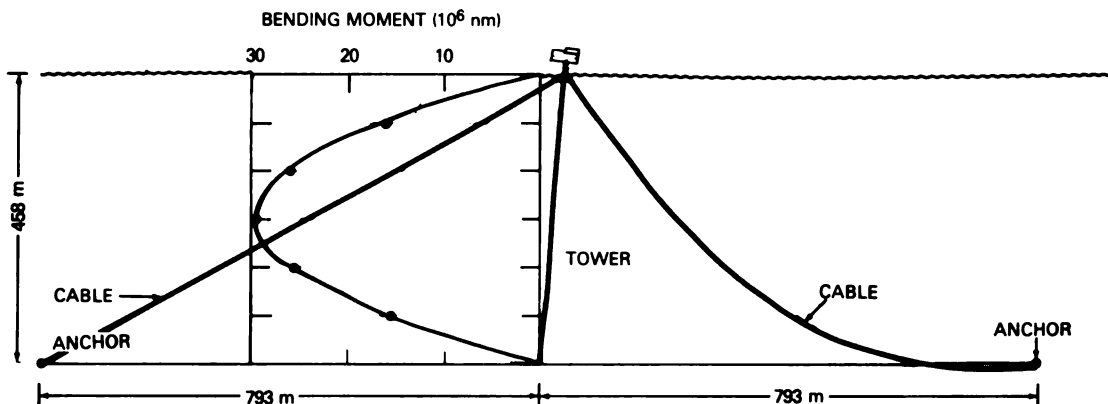


Figure 12. Calculated displaced configuration of a loaded two-dimensional guyed tower. Current and wind are from left to right. Superimposed is a plot of the resulting bending moment along the tower.

code which has been used to develop computation techniques and algorithms and to solve problems such as the one shown above.

It is expected that no major new techniques will be required in a more realistic 3-D code soon to be developed. Additional features to be included in this more comprehensive code are provision for tower twist and for tower-cable attachment locations which may be offset from the tower center line. The 3-D program should provide a significant improvement over existing capabilities for solving force and displacement problems for guyed structures.

[Sponsored by ONR]

Reliability of Wire Rope, by F. R. Stonesifer and H. L. Smith, *Ocean Technology Division*

Historically, the Navy has been closely associated with the use and development of rope. With increased requirements for stronger flexible tensile structural members, more and more wire rope has been put into service. Today, military activities and private industry are heavily dependent on wire rope. The energy crisis, for example, has stimulated increased activity in surface coal mining and, consequently, has rekindled interest in large-diameter (25 to 100 mm) wire ropes. Here, even slight increases in rope life could increase productivity substantially without significant increases in capital investment. It has been estimated that an improvement of only 10% in the average rope life in about 120 large drag-lines would permit removal of an additional 3

million cubic meters of overburden each year. Wire rope failures can be catastrophic, and replacements involve long down-time and reduced productivity. NRL is currently investigating the reliability and useful life of medium-diameter (6 to 25 mm) wire rope slings or pendants commonly used for lifting and hoisting in the Navy.

Considering the large quantities of wire rope presently in use, and our dependence upon it, there is surprisingly little scientific knowledge about its optimum design and use. Certain preferred constructions and materials have evolved over the years, mostly through trial and error. In hoisting applications and general design, for example, the rated load (or allowable use load) generally is taken as 1/5 of the "catalog strength." The catalog strength is usually a somewhat conservative representation of the rope's ultimate tensile strength (UTS). For other purposes, the specified rated load may vary from 1/12 to 1/2 the breaking strength of the rope.

Wire rope components generally are used until they either fail or are rejected through visual inspection. An inspector often uses his hand, bare or gloved, sliding it along the rope to locate external breaks in individual wires. In tensile applications, replacement is then usually based on the number of such breaks per length of rope. For ropes running over sheaves, worn and flat outer wires may also be cause for rejection. The objective of the NRL investigation has been to eliminate costly failures and premature replacements by a sound scientific

approach to optimize the selection, use, and replacement criteria for wire rope.

Pendants of 6 mm diameter wire rope were cyclicly tested in tension with a sinusoidal load-time profile. Each was tested for fatigue endurance load, the load at which the cyclic life can reasonably be expected to exceed 10^6 cycles. The wire ropes tested included a variety of constructions and materials and for most, the fatigue endurance load was found to be approximately 1/5 of the UTS regardless of material or construction. This is consistent with the present practice of using 1/5 of the UTS for the allowable working load in hoisting applications.

Breakup of individual wires in a rope is associated with fatigue damage and reduction in tensile strength. The only wires visible for inspection are in the outer layer of the outer strands, those referred to as the "E" wires. NRL found that the density of broken "E" wires is a poor indication of the strength of the rope or its remaining life (Figure 13). Break count depends on the cyclic load during the rope's life as well as on its construction and material. The inadequacy of the visual inspection criterion is dramatically illustrated by the fact that all ropes tested showed relatively few broken wires (or none) just before they failed in tension cycling at only 1/5 of the UTS.

An important finding of this study is that fatigue life (number of cycles before failure) can be increased by overloading. The crack-

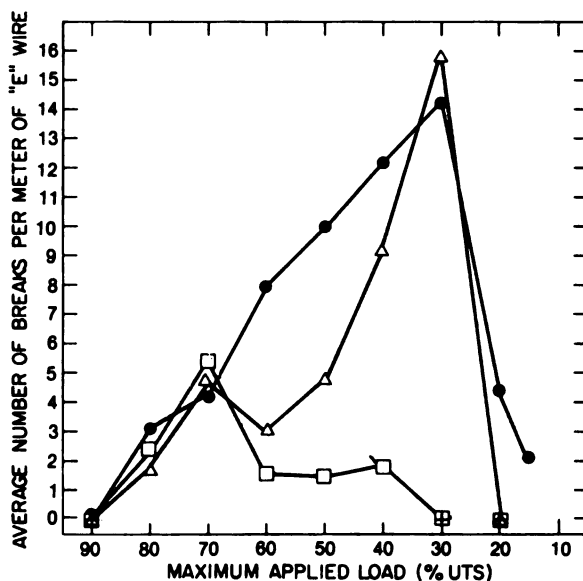


Figure 13. Density of broken outer wires as a function of maximum applied cyclic load for three different types (3 symbols) of 6 mm o.d. wire rope. Each point represents a separate rope pendant tested to failure. Breaks were recorded just before ropes parted.

retardant effects of overloading have been known for fatigue in bulk metals, but never demonstrated for wire ropes until this study. Overloads not only retard crack formation but primarily extend fatigue life through an increase in stiffness. The higher loads settle the wires, reducing the slack in individual wires, and thus produce a more even stress distribution within the rope. Then the rope (as a

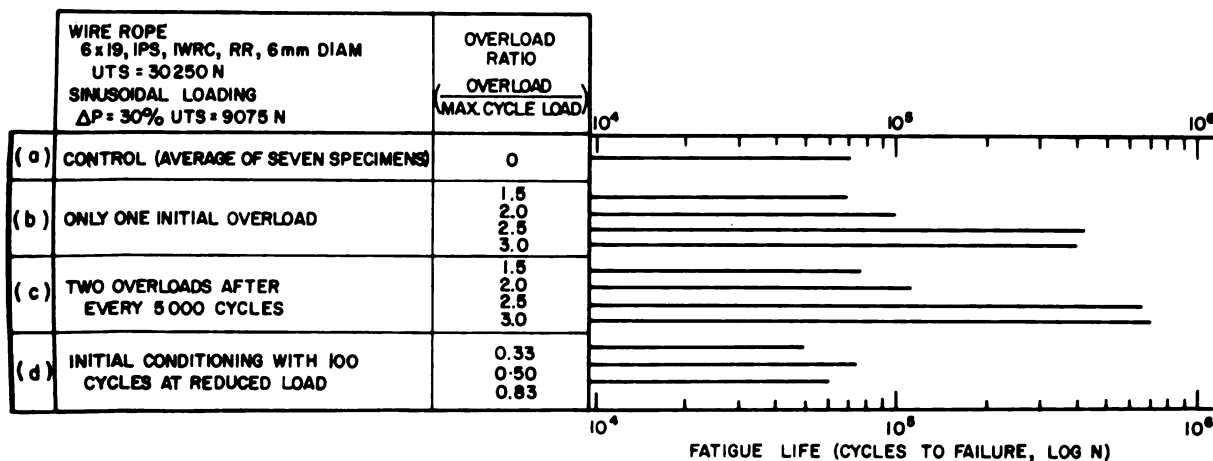


Figure 14. Variations in fatigue life of a wire rope due to cyclic loading with various overload sequences. Overloading can extend fatigue life (bar lengths to right) by nearly an order of magnitude.

structure) appears stiffer (less compliant) with less elongation and intra-wire friction on subsequent loadings at lower tension. The beneficial reduction in compliance can be achieved with only one initial overload.

The effect of loading sequence on fatigue life is illustrated in Figure 14 for one wire rope type and load excursion. Note that any overload will generally extend the specimen's life compared to that for the control samples (14(a)). The maximum overload benefit is obtained through periodically repeated overloads (14(c)). However, just one initial overload (14(b)) will give nearly as long a life and seems much more practical than the periodic overloading. The common industrial practice of "working-in" a new rope at a reduced load (14(d)) does not appear to offer any significant advantage and may even be detrimental.

Results of this study have shown why and how wire rope fails when subjected to cyclic loading. The investigation will continue to seek other ways to increase the useful life and reliability of wire rope components. The basic data accumulated should assist in better and more efficient use of wire rope in future structural designs.

[Sponsored by SSPO]

Flashover Voltage in Underwater Sound Transducers, by L. P. Browder, *Underwater Sound Reference Detachment*

The development and use of high-power sonar transducers by the Navy resulted in a need for high-voltage drive on the piezoelectric elements. This has increased the importance of electrical discharge phenomena, ranging from corona to arcing, that have been identified as responsible for a substantial percentage of failures in transducers.

Sonar transducers have active elements of lead zirconate titanate (PZT) ceramic that are the main insulating barriers to the high-voltage drive. A metal transducer housing encloses these elements in a gaseous fill fluid with insulating properties. Common dry air or nitrogen, often used for this purpose, is the weak link in the insulation system. This vulnerability can be reduced by substituting electronegative gases such as sulfur hexafluoride (SF_6) and the perfluorocarbon homologous series with formu-

lae $\text{C}_n\text{F}_{2n+2}$ and C_nF_{2n} , which are known to have better insulating properties. A properly chosen gaseous fill fluid for transducers will substantially improve the high-voltage operation and reduce the electrical failure rate.

One of the most common electrical breakdown mechanisms in transducers is surface flashover, or "creepage," an arcing phenomenon between sharp electrode edges or on the PZT ceramic surface. It occurs in air at less than half the voltage at which breakdown would occur across the same distance in a uniform electric field. The deleterious effects of such arcing in transducers are burned electrodes, eroded PZT surfaces, and changes in the gaseous fill fluid composition. Also, the acoustic outputs of transducers become distorted when flashover causes the drive voltages to collapse.

Flashover voltage (V_f) is being investigated at NRL in simulated transducer environments of air, nitrogen, SF_6 , and the perfluorocarbon gases. Results have shown that this parameter varies exponentially with inter-electrode distance (d) and fill-fluid pressure (p) according to the general relation

$$V_f = Kd^n p^m.$$

The factors K , n , and m are constants determined for each gas. Results for some of the gases at atmospheric pressure are shown in Figure 15.

In sonar transducers, the gaseous fill fluid may become contaminated by air or water vapor as a result of faulty filling procedures, system leaks, or slow permeation through elastomer materials. Tests to determine the effect of these contaminants on the electronegative gases indicate that small amounts of air change the flashover voltage very little. Small amounts of water vapor in an air-filled system actually cause small increases in the flashover voltage, but such minor benefits are nullified by still other detrimental effects of the water vapor.

Arcing and corona discharges can chemically modify the gas molecules of a fill fluid. Moderate amounts of arcing in the simulated transducer environment indicate, however, that the flashover voltage level is not significantly changed even though the electrodes and PZT ceramic are burned. Arcing in the perfluorocarbon gases produces a brownish deposit

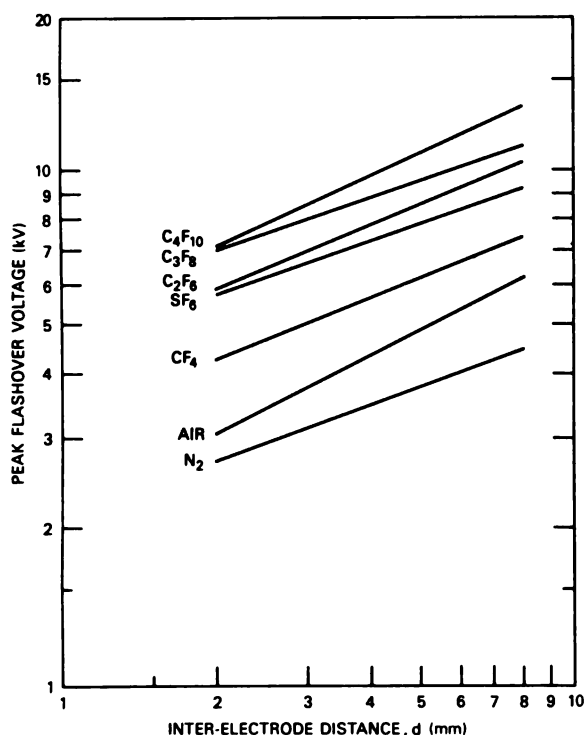


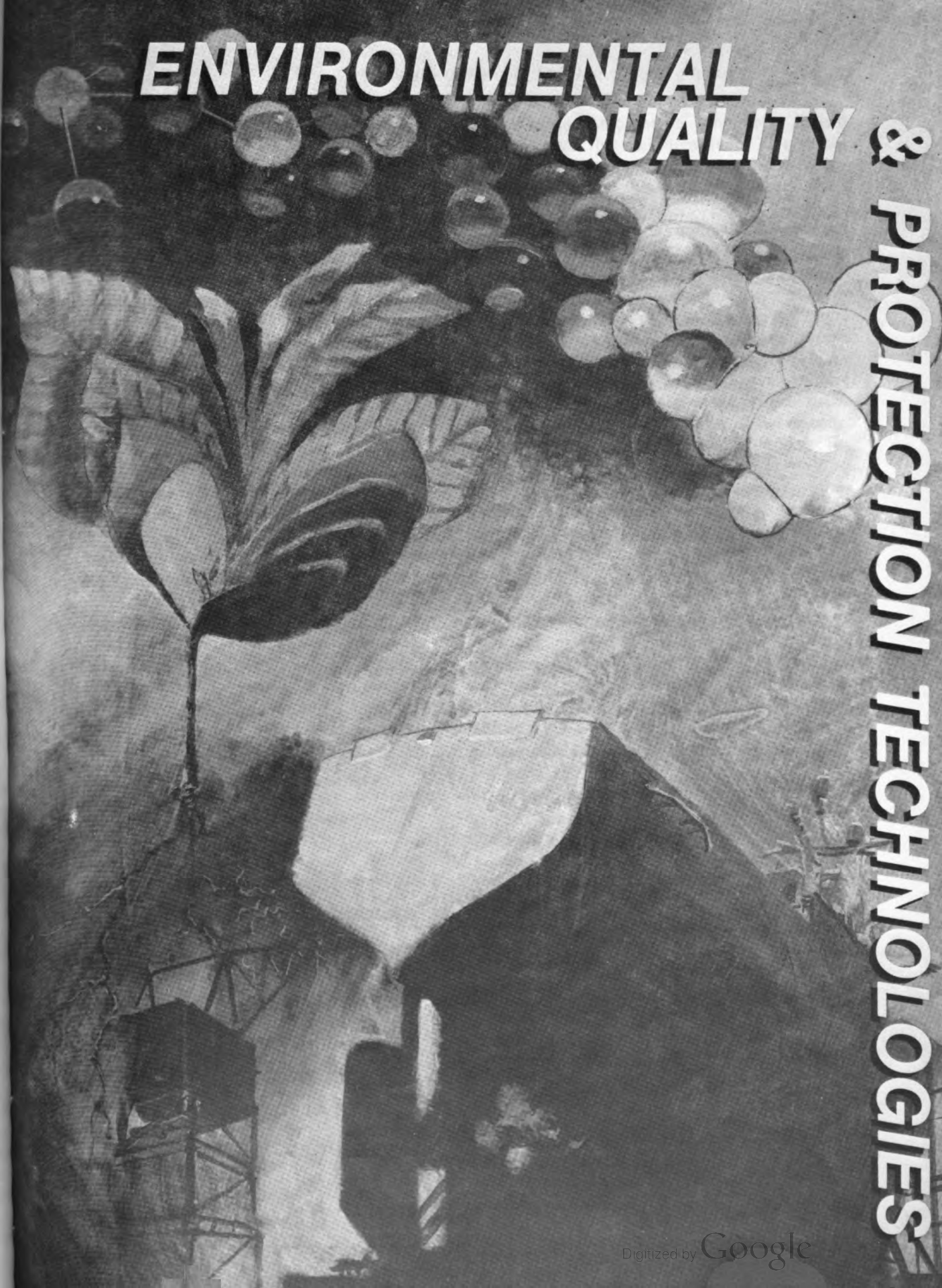
Figure 15. Inter-electrode distance (d) vs peak flashover voltage of PZT ceramic using various fill gases at 1 atm

resembling lampblack (probably carbon) on the PZT surface. The arc probably reduces the more complex perfluorocarbon molecules to CF_4 but there is no indication of fluorine gas. Arcing in SF_6 produces gases having odors resembling sulfur dioxide (SO_2) and hydrogen sulfide (H_2S). A small quantity of white precipitate (probably sulfur) is formed and the glass test cell is etched, indicating fluorine gas.

Further identification of materials and methods for increased tolerance of high vol-

tages is part of a long-range program to increase the reliability and life of sonar transducers. The problem involves not only selection of proper materials and methods but the optimum design for electrode and solid insulation configurations as well. Additional developments hold the promise of more efficient, higher power, longer life transducers to improve Navy underwater communications, navigation, and target location systems.

[Sponsored by NAVSEASYS COM]



ENVIRONMENTAL QUALITY & PROTECTION TECHNOLOGIES

ENVIRONMENTAL QUALITY AND PROTECTION TECHNOLOGIES

The Navy's ability to perform effectively depends not only on its material capabilities and sophistication but also on its ability to assure the functional levels of its systems and its people. The importance of the knowledge necessary to ensure adequate protective techniques and safe environmental conditions is recognized by the Laboratory and is being pursued in a variety of biotechnological research investigations.

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Spectroscopic Measurements of Microwave Effects in Model Biological Cell Membranes,
by J. P. Sheridan, *Optical Sciences Division*

With the increasing use of microwave-emitting devices in communications, navigation, *etc.*, has come growing concern about the possible health hazards of exposure to nonionizing radiation. Of particular concern are Navy vessels and installations with large amounts of microwave equipment. Experimental research has indicated that reversible microwave effects may occur in animals exposed to low to moderate power levels of radiation. Some of these observed effects have been interpreted in terms of perturbations of biomembrane structure and function.

Biological membranes are bilayer assemblies consisting mainly of proteins and lipids. Specific proteins mediate distinctive functions of membranes, with the lipids creating a suitable environment for the action of these proteins. Phospholipids are the major class of membrane lipids, and several physical methods have shown that many phospholipids in both model and naturally occurring cell membranes undergo thermally induced phase transitions. These transitions often occur in the biological temperature regime (35 to 45°C) and have been implicated in a wide variety of physiologi-

cally important membrane functions. Indeed the evidence is that cell membranes "live within the phase transition;" thus any stress that perturbs them from this condition alters their function in some degree.

NRL scientists are employing Raman and fluorescence spectroscopy to probe the effects of continuous wave (CW) microwave radiation on molecular order and temperature of synthetic and naturally occurring phospholipid membrane preparations. Two kinds of model membrane systems are being studied (Figure 1); the multilamellar liposome systems are good models for multilayer membrane structures such as the myelin sheath of nerve cells, and the unilamellar vesicles are models for single-bilayer cell membranes.

These model membrane systems were initially examined by laser Raman spectroscopy to learn about the effect of temperature on molecular order within the membrane bilayer. Raman spectroscopy is particularly potent for studying the thermally induced order-disorder phase transition characteristic of any chosen phospholipid bilayer. The reason is that the Raman spectrum of a phospholipid molecule is dominated by the environmentally and conformationally sensitive vibrations of the lipid hydrocarbon chains that constitute the interior

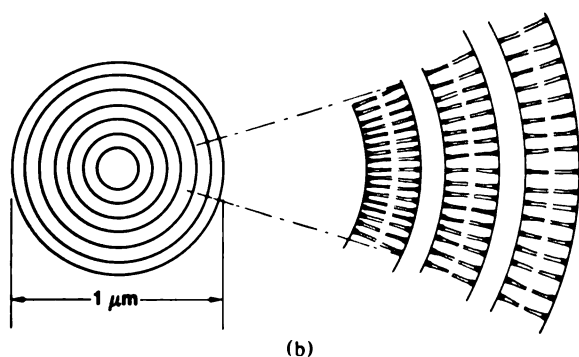
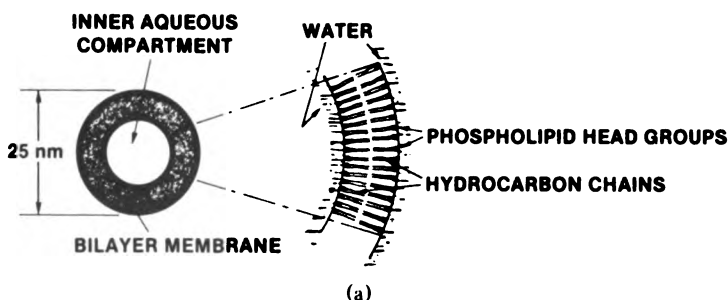


Figure 1. Model membrane systems. (a) Unilamellar bilayer vesicle, (b) multilamellar liposomes.

of the membrane bilayer. Many of these vibrational modes markedly change intensity at a phase transition, because of cooperative conformational changes in the lipid chains which reflect an increase in the relative fluidity of the bilayer. A quantitative measure of the change in fluidity can be obtained by measuring the change in intensity of one of the hydrocarbon chain vibrations (such as the skeletal band at $\approx 1130\text{ cm}^{-1}$) vs the intensity of a reference vibration not sensitive to temperature or conformational change. Such a reference vibrational band is the 720-cm^{-1} band that occurs in the polar head group moiety of the phosphatidylcholine lipids. A commonly occurring member of this class of lipids is dipalmitoyl phosphatidylcholine (DPPC) with hydrocarbon chains 16 carbons long. This phospholipid is a useful membrane model since it displays phase transitions in the biological temperature regime. Plots of the intensity ratio (I_{1130}/I_{720}) of the two bands as a measure of bilayer fluidity for the two types of membrane models prepared from DPPC (Figure 2) show that the multilamellar structures of DPPC have a sharp first-order transition at $\approx 41^\circ\text{C}$, preceded by a small pretransition at $\approx 35^\circ\text{C}$, and that unilamellar vesicles of DPPC display a single broad transition centered around 37°C . These plots of relative fluidity or bilayer temperature (as measured by Raman intensities) provide a set of baseline data for the microwave studies.

Also, the bulk temperature of the biological sample must be monitored without distort-

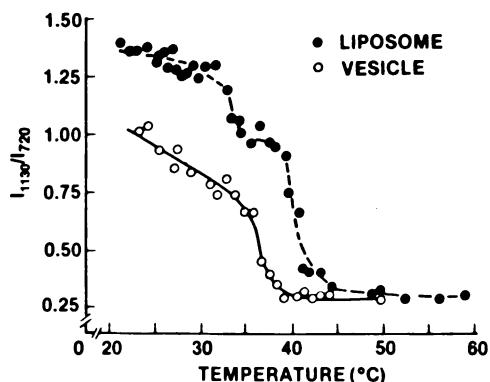


Figure 2. Melting curves for DPPC multilamellar liposomes and unilamellar vesicles derived from the change in skeletal-band (1132 cm^{-1}) intensity relative to the temperature-invariant C-N stretch (720 cm^{-1})

ing the microwave field and without the monitor itself being influenced by microwave-induced currents. NRL scientists have developed such a monitor using the temperature-dependent frequency of the R1 fluorescence line of ruby. Ruby is a good choice because it is insoluble in biological media and is nonconducting. Furthermore, its fluorescence lines do not interfere with the Raman spectrum of the membrane if an excitation wavelength of $<570\text{ nm}$ is used. Also, its fluorescent linewidth is sufficiently narrow for precise determination of the frequency. Thus, with use of the 514.5-nm line of an argon-ion laser, Raman/fluorescence experiments on biomembrane samples in excess water containing small fragments ($<10\text{ nm}$) of ruby can be conducted with minimal perturbation of the incident microwave field.

In a typical experiment, a multilamellar preparation of DPPC in excess water containing a fragment of ruby was sealed in a thin-walled capillary and maintained at a temperature just below the main phase transition ($38.5 \pm 0.15^\circ\text{C}$) in a thermostated anechoic chamber. The sample was irradiated at various power levels (1 to 25 mW/cm^2) with CW microwave radiation at 2.4 GHz . Raman and fluorescence spectra were obtained during each radiation exposure. The relative degree of fluidity (or temperature) of the bilayer interior as indicated by I_{1130}/I_{720} is shown in Figure 3. For the multilamellar preparation (solid curve), there is evidence of a microwave-induced effect with a threshold in the region of $\sim 10\text{ mW/cm}^2$. It appears that a power level of $\sim 25\text{ mW/cm}^2$ is sufficient to increase the bilayer fluidity (or temperature) to a level equivalent to that observed just above the main phase transition. Meanwhile, the change in the sample's bulk temperature (as measured by the ruby fluorescence technique) is much smaller, with a maximum rise of $\sim 1^\circ\text{C}$ at an incident power density of 25 mW/cm^2 .

The experiments were repeated with unilamellar vesicle preparations with the chamber temperature maintained at $\sim 36^\circ\text{C}$, just at the onset of the vesicle phase transition. In this case, no increase in membrane fluidity (as measured by the Raman intensity) or in bulk temperature (as measured by the ruby tech-

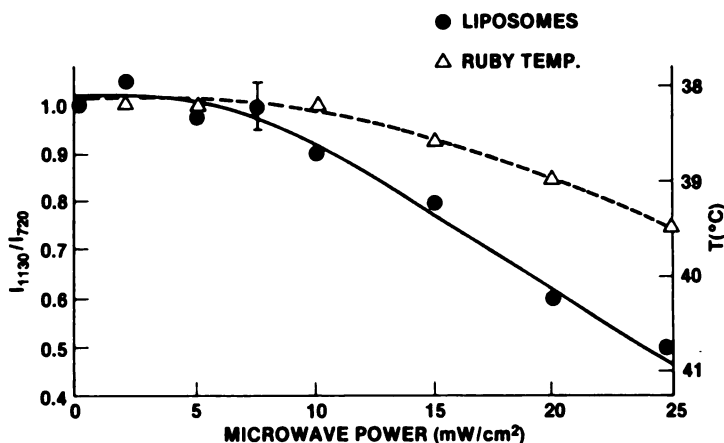


Figure 3. Relative change in fluidity temperature as a function of microwave power for DPPC liposomes

nique) was observed in the range of incident power density from 1 to 25 mW/cm².

These results suggest that, for the multilamellar bilayer structures, a temperature difference exists between the interior of the bilayers and the aqueous environment external to the multilamellar liposomes. On the other hand, there appears to be no difference between bilayer temperature and bulk temperature in the unilamellar case. The results suggest that certain types of membrane structures may be perturbed by fairly low levels of microwave radiation. However, much more work needs to be done on complex biological systems involving "real" membranes before the question can be satisfactorily resolved.

[Supported in part by the Naval Medical Research and Development Command (N.M.R. & D.C.)]

Clean Air for Submarines, by J. J. DeCorpo, Chemistry Division

The need to ensure the effectiveness of the nation's nuclear submarine Fleet requires the maintenance of safe, reliable submarine atmospheres. The absence of such a reliable atmosphere during the long operational patrol of the typical FBM or nuclear attack submarine can expose the crew to a multitude of physiological and psychological stresses sufficient to alter, misdirect, or even abort the submarine's mission.

The major constituents of the submarine's atmosphere are nitrogen, oxygen, and

a trace of argon. However, relatively small but varying amounts of carbon dioxide, carbon monoxide, methane, hydrogen, and traces of a variety of other compounds constitute the major threats to submarine habitability.

Over the years, NRL's scientists have developed systems and techniques to monitor and characterize the submarine atmosphere. One such development was NRL's Central Atmosphere Monitoring System (CAMS), incorporating a mass spectrometer, which routinely monitors the atmospheres of several submarine compartments. This system has been successfully incorporated into the Fleet.

Yet another NRL accomplishment is the periodic, comprehensive characterization of the submarine's atmosphere, which required the design of new sampling and statistical methodology, as well as sea trials.

In preparation for the sea trials, NRL scientists designed atmospheric sampling methodology to obtain both time-averaged (average concentration during a watch) and instantaneous (deviations from the average) concentrations. They then conducted laboratory studies using the statistical method of variance to determine the effects of different contaminant concentrations and other sources of variability in the overall sampling and analysis methodology. The atmosphere sampling plan was statistically designed to minimize the necessary number and types of samples without compromising the experimental objective of determining the effects of time under way, kind of compartment, and shipboard operations.

During 1978, sea trials were conducted aboard one submarine on its last cruise before being overhauled, and aboard another that had recently been overhauled. A subsequent comparison of results would indicate whether or not the overhaul operation introduces contaminants.

The NRL experiments provided much-needed data for a series of studies at the Naval Submarine Medical Research Laboratory to identify physiological effects of long-term exposure to atmospheric constituents at concentrations above natural values. In addition, the NRL data are important to naval engineers. For example, the data have been used in evaluating the efficacy of the carbon dioxide scrubbing equipment. Indeed, recent redesign of the scrubbers, based partly on NRL's data, should reduce CO_2 by more than 30% aboard the "Trident" class submarines.

Other major contaminants include carbon monoxide (CO), chiefly from smoking and cooking, methane (CH_4) from metabolic processes, and Freons from the air-conditioning and refrigeration systems. The profiles of major contaminants are shown in Figure 4. Methane and the Freons, although not easily removed from the atmosphere, generally are of little concern at the levels recorded because of

their relative nontoxicity. During submergence, the methane concentration increases because of normal metabolism. However, the increase in Freon-A with time indicated a leak in the refrigeration system, information useful to the engineering officer.

Aboard each submarine, the level of total hydrocarbon exposure (aliphatics plus aromatics minus methane) is monitored by the crew, using NRL-developed equipment. A typical time-weighted average exposure is shown in Figure 5 during normal operating conditions of a postoverhaul patrol. The levels observed, well below BUMED limits, did not differ significantly from preoverhaul averages, indicating that the controls on types and quantities of materials used during shipyard overhaul apparently were effective.

The life-support system includes electrostatic precipitators for removal of particulates and aerosols, mostly products of smoking and lubricants. Shipboard particulate analyses indicate that, although the size distribution has been relatively constant, concentrations are an order of magnitude lower than those observed 10 years ago, an indication of improved effectiveness of the equipment. The size distribution has a maximum at ≈ 0.4 micrometers, which is typical of stale cigarette smoke. A

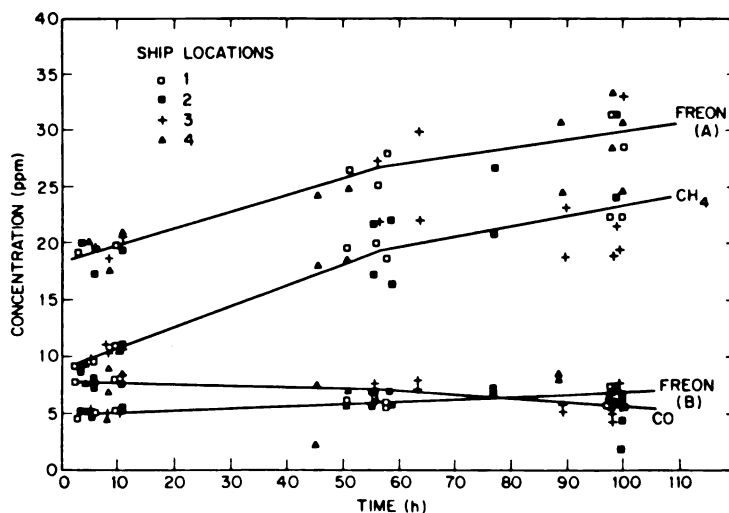


Figure 4. Concentration of four major atmospheric contaminants with increasing time of submergence. Carbon monoxide (CO) from smoking and cooking is adequately controlled by the catalytic burner, and Freon B is effectively contained in the air-conditioning system. However, methane (CH_4) and Freon A, both relatively innocuous but difficult to scrub, increase with time of submergence. The increase in Freon A indicated a small leak in the refrigeration system.

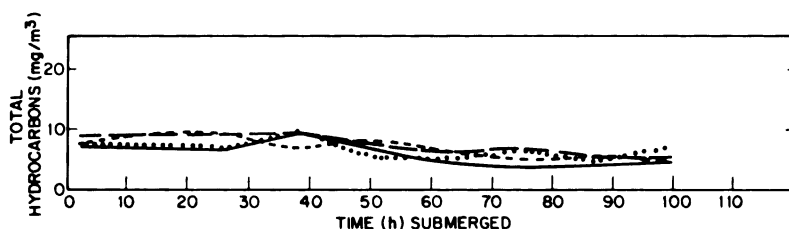


Figure 5. Total hydrocarbons measured in four different compartments during a four-day period of submergence. Other NRL observations, which showed higher hydrocarbon levels, have led to remedial procedures to reduce contamination.

number of shipboard analyses were performed for contaminants, such as ozone, which are difficult to sample. Because of previous NRL findings of relatively high ozone concentrations that are both toxic and deleterious to equipment, the precipitators were redesigned. The absence of detectable ozone in their vicinity is another measure of improvements made in recent years in life-support systems.

NRL's submarine atmosphere control program is a continuing program and has contributed significantly over the years to clean air aboard nuclear submarines. Earlier development of CAMS is leading to an improved second-generation system (CAMS II). The NRL-developed sampling methodology is providing valuable data to the Navy's medical community to use in physiological evaluation of contaminants. Furthermore, it provides necessary impetus to the design of even better shipboard purification systems.

[Sponsored by ONR, NAVSEASYS COM, and NAVSEC]

An Improved Shipboard Fire Detection System, by T. T. Street and J. I. Alexander, Chemistry Division

Significant advances in off-the-shelf fire detectors have been made in the civilian sector where sensors are exposed to relatively stable environments. However, these detectors do not function as effectively aboard ships where they encounter large, rapid changes in temperature, humidity, and air flow. These environmental changes tend to increase the false-alarm rate and often cause the detector to delay or even fail to alarm at all.

NRL scientists, active for many years in fire research, have developed an improved pro-

totype fire detection system for use aboard naval ships. The system (Figure 6) incorporates a number of new ideas and concepts including microprocessor control, variable sampling rate, two kinds of sensors, and several levels of alarm. These advances reduce the number of false alarms and allow reliable, early fire detection in extreme and dirty environments.

The environmental effects on false-alarm rates are greatly reduced in the NRL system by an environmental averaging technique. In the sampling detector (see Figure 7), ambient air is drawn continuously into a dilution flask by a small fan, providing a continuing dilution of the flask contents which are monitored for combustion products. When possible combustion products are first detected, the fan speed increases (up to four times) in proportion to the measured amounts. This flushes out short-term intrusions, such as that produced by a drop of oil on a hot manifold, thus reducing an important cause of false alarms. The dilution flask also helps to isolate the sensors from rapid changes in air such as drafts and temperature and humidity fluctuations, which can also cause false alarms.

To cover a wide range of fire types, the system uses two ionization sensors to monitor the contents of the dilution flask. Eventually, a photoelectric sensor, under development, will replace one of the ionization sensors in the system. These two types of sensors respond to different particle sizes. When combined, they will provide detection sensitivity over a wider particle range than either type can provide alone.

The heart of the system is an associated microprocessor that controls the response to detection signals from the sensors. The

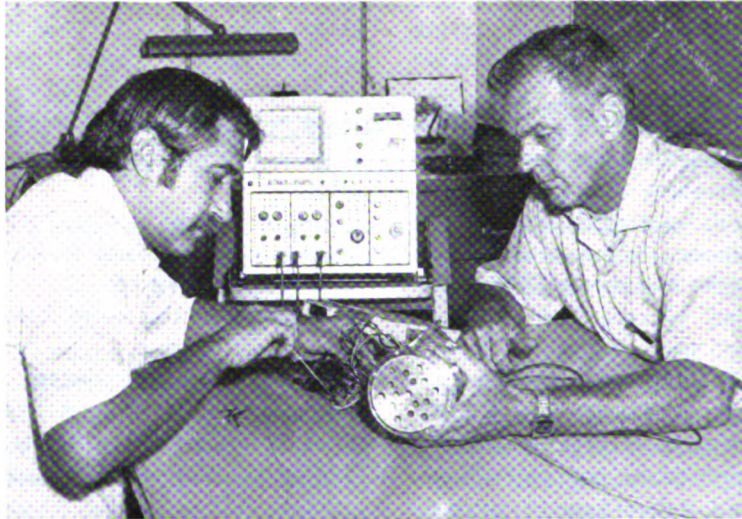


Figure 6. T. T. Street (l) and J. I. Alexander make final adjustments to detector head before conducting tests of the NRL Fire Detection System at the Philadelphia Navy Yard. The cylindrical head contains sensors, fan, dilution flask, and electronics controlled by an external microprocessor. Eventually the microprocessor will be incorporated into the detector head as well.

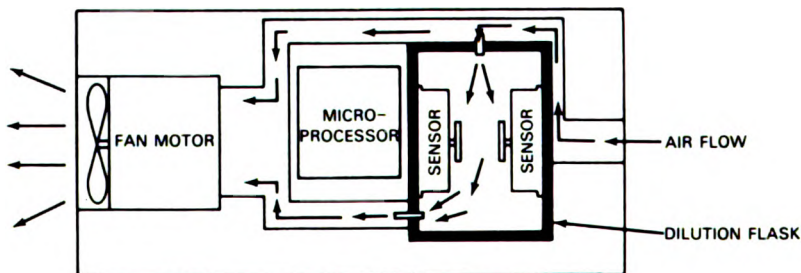


Figure 7. Schematic of the NRL Fire Detection System. Ambient air is routinely siphoned into the dilution flask containing two ionization sensors (or an ionization sensor and a photoelectric sensor). When a potential hazard is sensed, the fan speed is increased up to four times, siphoning in air more rapidly, which results in confirmation or denial of an existing fire hazard.

processor's output scheme provides a graduated response to the perceived fire threat by adjusting fan speed and alarm levels, signaled by lights of different colors.

The prototype system is being subjected to a long-term test in the Philadelphia Navy Yard. Preliminary results based on more than 100 test runs at NRL are illustrated in Figure 8, which shows the relative response times of the NRL system and two commercial systems. For most types of combustion, the NRL detection system equaled or improved upon the response times of the commercial systems.

This system, when installed aboard naval ships, will provide more rapid and reliable detection of fires. The consequent gains in reaction time and effectiveness of fire fighting teams should provide major benefits by reducing injuries, ship damage, and time out of service.

A more fully developed shipboard system with a network of these detection systems would be able to monitor both direction and rate of fire spread. Ultimately, this enlarged system would become an integral part of a shipboard Fire Damage Control Center. Such a

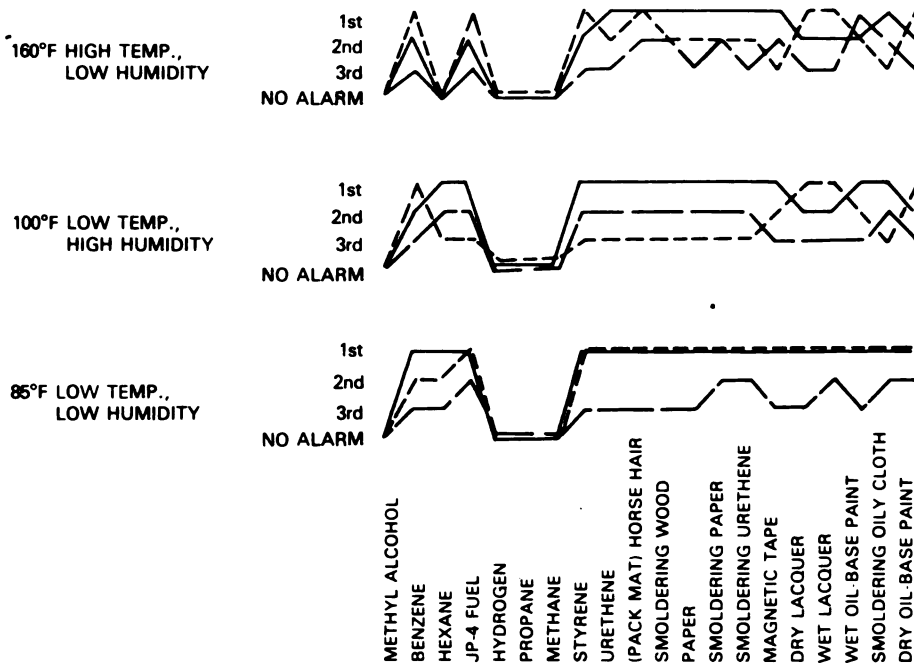


Figure 8. Test results for NRL-developed Fire Detection System (solid line) and two commercial systems (dashed lines) exposed to a variety of combustion sources under different combinations of temperature and humidity. The vertical scale indicates the order in which the three alarms activated. For most types of combustion, the NRL system equaled or improved upon the quickness of activation of the other systems tested.

center would monitor many shipboard spaces from a central location to detect and follow the progression or regression of on-board fires. With the incorporation of available diagnostic techniques, this center could also display the types of combustibles present and indicate the best method(s) to extinguish the fire in a given location.

The NRL detector system should also have important applications, other than aboard ships, because of its inherent advantages. Industrial plants, mines, and aircraft generate the kinds of environmental variations that require fire detector systems with low false-alarm rates and high sensitivity. Installation of the NRL system in such facilities could provide a higher degree of protection than is normally available with existing commercial systems.

[Sponsored by NAVMAT]

Nontoxic Marine Fouling Prevention, by G. I. Loeb, *Ocean Sciences Division*

Preserving the hydrodynamic smoothness of high-speed hulls has become a major naval

need in recent years. Growth of marine plants and animals on hulls has been recognized from antiquity as a cause of deteriorating vessel performance, and methods of avoiding or slowing such biological fouling have an extensive history. However, the degree of success achieved with past and current practices depends upon the introduction of toxic agents into the sea; antifouling materials and coatings are successful as long as they release a sufficient quantity of toxin to maintain a toxic layer of seawater adjacent to the protected surface. To reduce the need for release of toxins into the environment, and to increase our understanding of the basic mechanisms involved in biological attachment, investigations are being carried out on factors other than toxicity that affect the attachment of fouling organisms.

Immersion of nontoxic materials in natural waters is known to initiate a sequence of events that eventually leads to a complex mature community of plants and animals. Certain species are observed to "pioneer," colonizing surfaces freshly introduced or recently cleared; other organisms are recruited later.

Microorganisms have usually been the initial settlers, with macroscopic foulers following. NRL is studying the effects of material surface properties upon the colonization rates of marine microbes and some of the larger fouling organisms.

In collaboration with a colleague from the University of North Wales, we isolated colonies of several types of marine microorganisms from glass and acrylic plastic which had been immersed in Atlantic coastal waters. A variety of materials was then exposed to sterilized seawater inoculated with bacteria grown from the isolated colonies, and the numbers of attached bacteria were counted after several hours.

Measurable physical properties that might influence attachment were then considered for investigation. The contact angle, θ , of a liquid with a solid surface (measured at the edge of a drop, or at a bubble within the liquid (Figure 9)), is an important parameter characterizing solid-liquid interactions. The numbers of bacteria attached after 2 hours to the variety of materials used are plotted vs water contact angles on these surfaces in Figure 10. A bacterial preference for the higher-contact-angle (hydrophobic) materials such as Teflon or polyethylene, rather than for the low-contact-angle (hydrophilic) materials like glass or mica, is evident.

The study of settlement preferences was then extended from microbes to representative types of the larger organisms that are well known to degrade ship performance, such as barnacles, tube worms, and bryozoa. Larvae of two species of bryozoans, for example, were allowed to settle on various surfaces, and they also showed a strong preference for hydrophobic materials.

The effect of prior microbial colonization upon subsequent attachment of bryozoan larvae also was studied, and significant differences were found among test surfaces. For example, hydrophobic polystyrene became more hydrophilic as microbial colonization increased, and the settlement of larvae was severely discouraged. However, the initially unattractive hydrophilic surface of clean glass became more attractive to larvae after microbial colonization. Since colonization placed organic material on the glass, its wettability was expected to decrease. This was corroborated by small

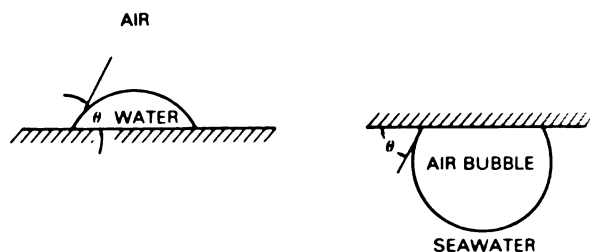


Figure 9. The contact angle θ of drops and bubbles is a measure of the wettability of a surface (wettability increases as θ decreases)

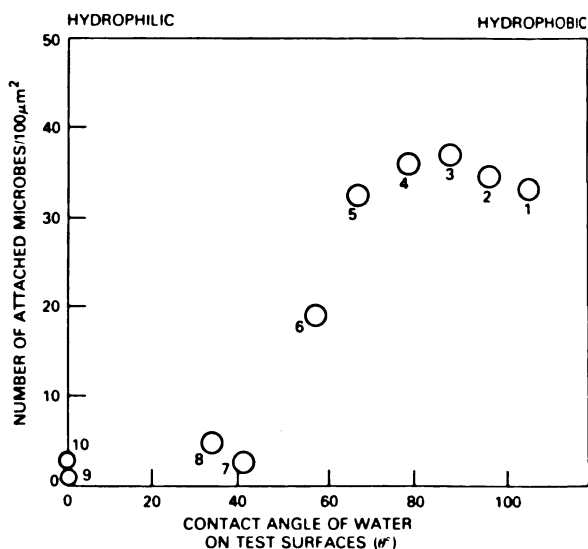


Figure 10. Relation of microbial attachment to material wettability as characterized by contact angle (See Figure 9). 1-Teflon, 2-Polyethylene, 3-Polystyrene, 4-Mylar, 5-Nylon, 6-Epoxy, 7-RF-Treated Mylar, 8-RF-Treated Polystyrene, 9-Glass, and 10-Mica

increases in the air-water contact angle as the surface became more attractive to the bryozoans.

These results are different from what might be expected on the basis of experience with clinical laboratory culture of biological tissues and organs, which attach and grow preferentially on hydrophilic materials (plastic ware for tissue culture is purposely treated to make it hydrophilic in order to encourage tissue attachment). Thus, it is apparent that different criteria determine the attachment tendencies of the marine organisms studied as compared with tissue and organ attachment in culture. These results also show that the well-known enhancement of fouling by microbial colonization observed on hydrophilic surfaces is not general,

since microbial films can have an inhibitory effect on attachment to hydrophobic materials.

Future work will explore the extent to which still other organisms show similar behavior, and will investigate the effects of other surface properties (particularly surface electrostatic charge and the adsorption of dissolved organic matter from seawater) on attachment and adhesion.

The extent to which fouling films can degrade the performance of marine equipment and systems depends upon the film properties. One approach to characterization of microbial films is described in the succeeding article.

[Sponsored by ONR]

Ultrasonic Detection of Marine Fouling Films,

by J. Jarzynski, *Acoustics Division*, and G. I. Loeb, *Ocean Sciences Division*

As pointed out in the previous article, increasing speeds of marine vessels have increased the significance of even very small degrees of biofouling. An emphasis on the energy efficiency of marine heat exchangers such as those used in the Ocean Thermal Energy Conversion project also makes the effect of minute growths particularly crucial. Microbial fouling, which is resistant to conventional antifoulants, thus assumes a new importance. Microbial colonization of surfaces is also an important early stage of dental and medical problems, but the work reported here is directed toward marine applications.

Conventional examination of microbial films is done by microscope. But microscopy imposes limitations on the type of specimen tested, and makes evaluation during the course of a test, or under realistic operating conditions, difficult if not impossible. The detection and characterization of microbial slime films, *in situ*, and in seawater, was thought to be a potential application of ultrasonic techniques, and a collaborative program was initiated between the Acoustics and Ocean Sciences Divisions to look for such methods. The objective was to develop a way to measure the thickness of wet fouling layers ranging from 2 to 50 μm .

In the first phase of the NRL program, the acoustic and viscoelastic properties of the fouling film material were investigated. These measurements were made with laboratory-

grown microbial films similar to the slime films found on metal surfaces in natural seawaters. It was observed that, physically, the fouling film is a gel-like material with a very low modulus of rigidity (5×10^5 Pa measured at 1 MHz). The sound velocity and density both were higher (by 1.2 and 2%, respectively) in the film material than in the saline solution in which the film was formed. Thus the acoustic impedance (the product of sound velocity and density) of the film material is expected to be relatively close ($\sim 3\%$ higher) to the acoustic impedance of the seawater. This implied that the ultrasonic echo from the film-seawater interface would be weak and, therefore, that direct detection of ultrasonic echoes from the slime-seawater interface would be impractical. Instead it appeared more promising to measure the effect of the fouling film by monitoring resonant vibrations of the metal sheet on which the film is deposited.

The experimental arrangement for this approach is shown in Figure 11. Sheets of thin (0.25 mm) aluminum were prepared with laboratory-grown microbial deposits 25 to 50 μm thick. These sheets were mounted as shown in the figure and insonified with sinusoidal pulses at frequencies near the fundamental resonant frequency of the metal sheet

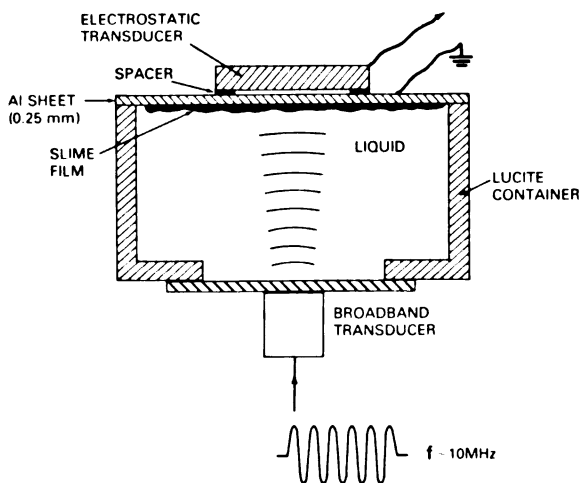


Figure 11. Feasibility demonstration for *in situ* acoustic detection of marine fouling. Narrow ultrasonic beam causes vibration of Al sheet between spacers. Growth of film changes resonant frequency and vibration amplitude of aluminum sheet. Electrostatic transducer measures amplitude and frequency of capacitance change in this system, and thus monitors slime growth.

(~10 MHz). The resulting vibrations of the aluminum sheet were monitored with an electrostatic transducer placed at the outside surface. The transducer had no contact with the sheet and therefore had negligible effect on its vibrations. The slime film was then wiped off, and the measurements were repeated. The data showed that the film had significant effects on both the resonant frequency (decreased by 1 to 2 kHz) and the amplitude of vibration (decreased by 3 to 6 dB). The resonant frequency can be measured very precisely, and the observed changes were at least 10 times larger than the minimum observable change (~0.1 kHz).

The measurements so far have demonstrated the feasibility of using ultrasound to detect microbial slime films. Current research is aimed at establishing a quantitative relation between the film thickness and the changes in resonant frequency and vibration amplitude of the metal sheet. This should permit *in situ* estimation of the extent of microfouling. Future work will be directed toward characterization of different types of microbial films, and correlation of their acoustic properties with those effects having engineering and biological significance.

[Sponsored by ONR]

Accurate Models of Biological Macromolecules, by W. A. Hendrickson, *Laboratory for Structure of Matter*

Research in the natural sciences is nearly always carried out in the context of a structural

image of the subject material. This image or model, whether founded on direct experiments or imagined from analogous structures, provides a conceptual framework on which to base both theory and experiment. In biochemical research, the relevant structural images are of the atomic arrangements in the large molecules of life such as proteins and nucleic acids. These macromolecular structures are far too complicated to derive from theoretical principles; they must be deduced from experiments. Generally, the only technique capable of producing a definitive picture of the three-dimensional atomic structure of a biological macromolecule is that of x-ray diffraction analysis of crystals.

X-ray structure analyses of molecular crystals usually proceed as indicated in Figure 12. Crystals are grown, reflection intensities are measured from the diffraction pattern, phases for the diffracted rays are evaluated by one of several means, a map of the electron-density distribution is prepared by Fourier transformation, and, finally, an atomic model is fitted to the electron-density map. The theory that relates the parameters of an atomic model to the diffraction pattern expected from such a structure is very well established. Thus, the accuracy of a model structure can be checked by comparing the diffraction pattern calculated from the model with the observed diffraction data. Moreover, this theory also provides a basis for adjusting the model to an optimal match with the observed data. Inasmuch as the model is related to the crystallographic data in a

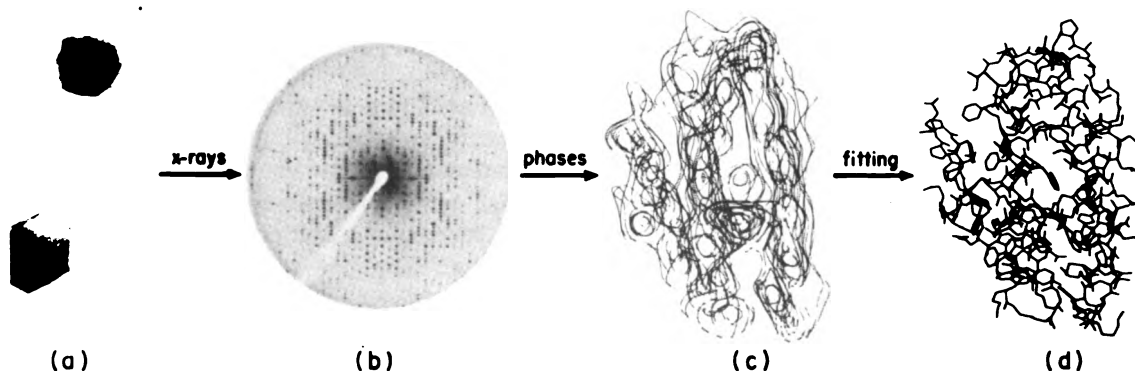


Figure 12. Protein crystallography pathway for NRL's study of the oxygen carrier, myohemerythrin. Crystals (a) of the macromolecule are subjected to x-rays to produce diffraction patterns (b). The analysis of the diffraction pattern yields an electron density distribution map (c) from which the atomic model (d) is derived.

highly nonlinear manner, these refining adjustments must be made in a converging series of iterations.

The power of crystallographic refinement for accurate definition of the parameters of an atomic model depends greatly on the extent to which the problem is overdetermined. Errors in parameter values vary inversely with the number by which the observational equations exceed the variable parameters. In the case of crystals of small molecules, observations normally exceed variables by at least 10:1 and refinement proceeds smoothly. In the case of macromolecules, however, the data are nearly always much more limited and may not exceed the number of parameters. Straightforward, classical refinement is then impossible.

New procedures have been developed at NRL to cope with the theoretical and computational problems associated with refining these atomic models against the often very limited diffraction data. This new method takes cognizance of extensive knowledge available about the chemistry and geometry of the components from which macromolecules are built. There are many known features including bond lengths and angles, planarity of certain groups, chirality (handedness) at asymmetric centers, nonbonded contacts, restricted torsion angles, and sometimes noncrystallographic symmetry. Such stereochemical knowledge has the form of an expected value for some feature (*e.g.*, a bond length) and the variance of the distribution of values it might take. These stereochemical data are included as additional observations in the refinement and are weighted according to the inverse of the associated variance. Entered in this way, they restrain the model to conform closely to known stereochemical rules while still permitting the expression of real deviations from ideality.

Refinement of macromolecular structures is frustrated not only by the relative paucity of measurable diffraction data but also by the sheer size of the molecules. Even computers as large as NRL's TI-ASC cannot handle such refinements as are done classically for small molecules. Thus only the dominant terms from the system of resulting equations are retained, and the conjugate-gradient procedure is used to solve for the improved parameter values. The calculations still require much computer power,

but programs optimized for the TI-ASC are relatively fast and effective.

NRL scientists have applied the new refinement procedures to six key biological molecules. Other laboratories around the world have applied the programs to many other important molecules. The initial program development was tested with data from University of Virginia collaborators on a calcium-binding protein related to muscle control. A second application examined a (snake-venom) neurotoxin in collaboration with biochemists at Wayne State University. Two protein structures previously developed at NRL, lamprey hemoglobin and sipunculan myohemerythrin, also have been refined. In the case of myohemerythrin, the model refinement has been an integral part of the structure solution. The new programs have also been used, in collaboration with scientists from MIT, to refine the structure of transfer RNA, a nucleic acid structure that plays a crucial role in translating the genetic message during protein synthesis. The most recent application has been to the antigen-binding fragment of an immunoglobulin, an antibody responsible for immunity to disease, in collaboration with colleagues at NIH.

This NRL work has demonstrated that meaningful refinement of macromolecular structures can be carried out, despite their very large size and the limited diffraction data, if stereochemical prior knowledge is taken into account. The methods are being adopted widely, most often with NRL's own computer programs. As a result, a new standard for the accuracy of published macromolecular structures is being established. Such accuracy is essential to the detailed understanding needed in many important areas such as enzyme activity, oxygen and electron transport functions, and drug design.

[Sponsored by ONR]

Molecular Structure of a Unique Plant Growth Promoter, by J. L. Flippen-Anderson, *Laboratory for Structure of Matter*

Plant growth regulators can be characterized as organic compounds that affect the physiological processes of plants. In practical terms they can be defined as either natural or synthetic materials that are applied directly to plants to alter their life processes or structures

in some beneficial way. These materials are playing an ever-increasing role in enhancing the production of agricultural products efficiently and safely. Growth enhancement applies not only to existing crops but perhaps even more to potential crops with implications in such areas as energy farms, and in the production of rubber and crude oil from plants. Although it has long been known that any bioregulated process can be influenced by organic chemicals, finding biodegradable substances that have both technical and commercial possibilities is difficult.

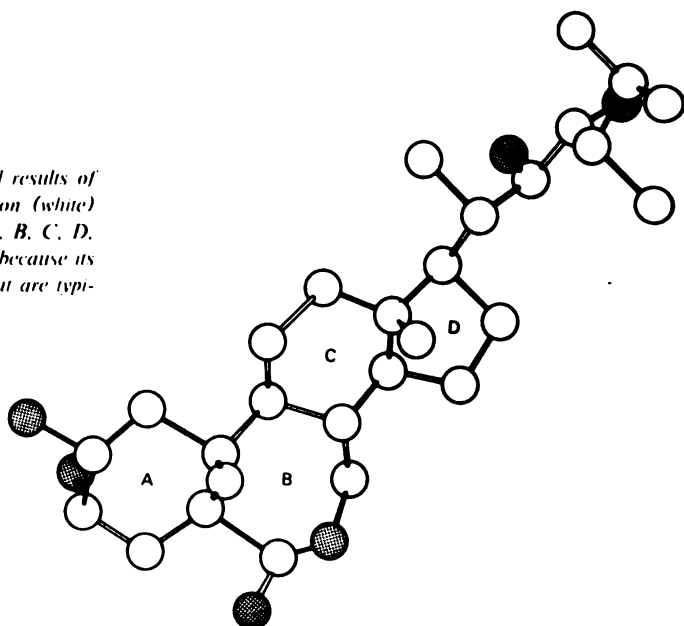
During a long-term USDA project to study natural materials that affect plant growth, it was found that extracts of *Brassica napus* (commonly called rape) pollen produce a novel growth-promoting effect when applied to young plants. The active component in the pollen was isolated by further chemical work, and it was found to produce a 200% increase in plant growth rate with applications as low as 10 ng per plant. It was expected that extensive further study of this material would yield valuable information for plant growth regulation. However, the yield of pure active molecule (brassinolide) from the original 40 kg of bee-collected pollen sample was only a few milligrams. The USDA project was forced to stop because of the insufficient amount of brassinolide available for study. The molecular structure remained essentially unknown.

However, the USDA's Northern Regional Research Center provided NRL with a few small crystals of brassinolide for further study. The x-ray intensities were measured by an automatic diffractometer and were assigned preliminary phases by symbolic addition, a procedure developed at NRL. This procedure produced a structural fragment, which was located in an electron density map of the molecule. The partial structure obtained was expanded into the full molecule when cycled through a tangent formula refinement. This procedure, also developed at NRL, refines the phases obtained from the known molecular fragment. Subsequent mathematical expansion of these phases provides an improved set of data which normally will yield a larger fragment of the molecule.

The procedures are repeated, each repetition leading to a larger fragment, until the completed molecule is mapped. The results of the structure determination are shown in Figure 13. The brassinolide molecule proved to be a steroidal hormone that differs distinctly from other molecules of this type in that ring B consists of seven atoms rather than the six that are typical of most steroids. The x-ray results also showed that each molecule of brassinolide cocrystallizes with one molecule of water.

With the structure determined, attempts are being made to synthesize the material for

Figure 13. Computer-drawn plot of the experimental results of x-ray structural determination of brassinolide. Carbon (white) and oxygen atoms (shaded) combine to form rings A, B, C, D, and a chain. Brassinolide differs from other steroids because its B ring consists of seven atoms rather than the six that are typical of most steroids.



further study and for ultimate large-scale production. The structure of a plant-cell promoter, 3-indoleacetic acid, was determined several years ago at NRL and the material is now in commercial production. The structural determination of brassinolide has given impetus to the investigation of other pollens for similar growth-affecting components. The ability to control the metabolism of crops could be one of the most significant quantitative gains yet achieved in agricultural production, and has important implications for food supplies, energy, and raw materials for organic synthesis.

[Sponsored by ONR]

Improved Estimates of Radiobiological Damage, by R. Silberberg and C. H. Tsao, *Laboratory for Cosmic Ray Physics*

New experimental data from collisions of high-energy protons with atomic nuclei, obtained at the Berkeley Bevalac during 1978, have permitted further progress in NRL's program of calculating nuclear breakup reactions at high particle energies. In recent years, NRL scientists have developed equations for precise calculations of these reactions and of the nuclear fragments formed. By applying these equations to nuclear reactions in biological tissues, the risks of leukemia and eye-lens cataracts have been assessed. Shielding requirements to reduce these risks also have been formulated.

Some of the new experiments were on the nuclear breakup of high-energy ions (1.9 GeV/nucleon) of iron. These experiments both confirmed the NRL iron-breakup calculations, and permitted further improvement of the breakup equations. New calculations with a revised computer code yielded improved estimates for the production rates in proton-iron collisions. For example, the calculated production rates of K, Ca, and Sc from p-Fe interactions were revised upward by 40%. In addition, computer codes were developed using a revised formulation for the energy dependence of the production rates in all proton-nucleus reactions. This revised formulation has improved the estimates for the energy dependence of the nuclear breakup probability of iron at energies above 1 GeV/nucleon. The new estimates are as much as 30% more accurate than previous values.

These improved estimates help in understanding the process of energy deposition in materials by heavy nuclei in cosmic rays, since the iron nuclei in the cosmic rays dominate this process.

The recent success of Berkeley scientists in measuring the energy spectra of nuclear recoils induced by high-energy protons has permitted preliminary NRL estimates of the biological risks which are more accurate than past calculations. The nuclear recoils are highly ionizing; hence their relative biological effectiveness (RBE) for radiation damage is high. It is estimated that a 5-milligray (0.5-rad) dose due to nuclear recoils induced by 1-MeV neutrons increases the probability for contracting leukemia as much as does an x-ray dose that is 70 times larger. Thus, including the newly measured energy spectra of nuclear recoils in the NRL calculations of the propagation of particles in matter and in biological tissue will yield better estimates of radiation risks.

Detailed knowledge of the properties of nuclear recoils generated by the protons also pertains to the radiation belts that gird the Earth. This knowledge has applications for space hardware design: the large depositions of energy in small volumes of microelectronic components can yield spurious background signals and possible permanent damage to tiny, sensitive components.

[Sponsored by ONR]

Computer Generation of Dose Distributions for Fast-Neutron Radiotherapy, by P. Shapiro, L. S. August, and R. B. Theus, *Radiation Technology Division*

A fast-neutron beam, produced at the NRL Cyclotron by bombarding a thick beryllium target with 35-MeV deuterons, is being used by the Middle Atlantic Neutron Therapy Association (MANTA) in a clinical trial to compare the efficacies of fast-neutron *vis-à-vis* conventional x-ray radiotherapy for the local control of malignant tumors. Precise control, collimation, and dosimetry of the neutron beam are required in order to deliver to the tumor the dose distribution prescribed by the physician.

Different sizes of neutron fields are obtained by using different beam collimators. The usual procedure is to achieve an optimal

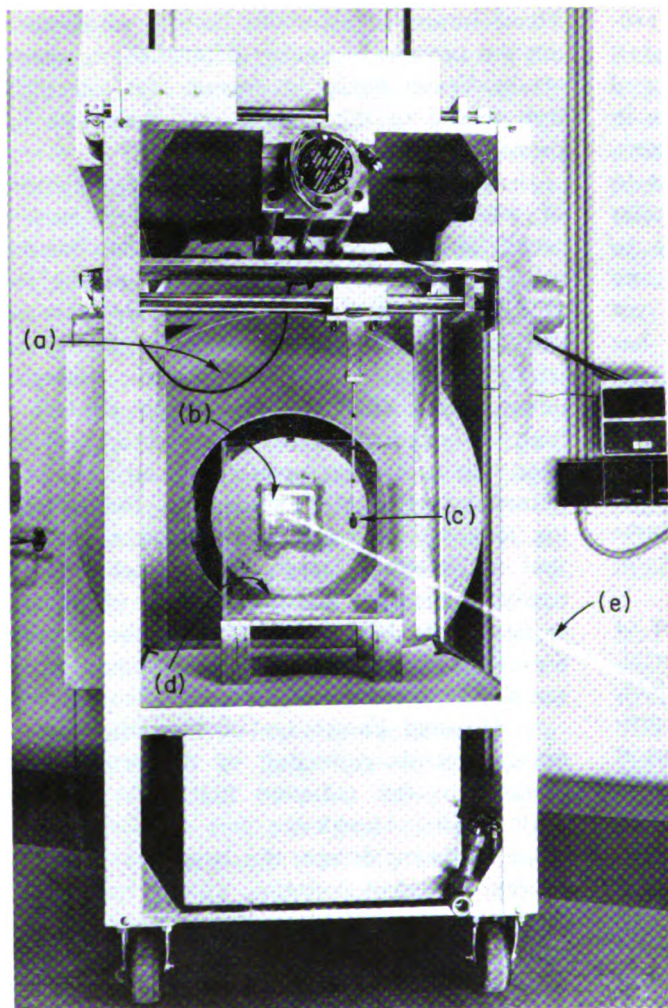


Figure 14. Dose distribution measurement apparatus in place in neutron therapy facility. The neutron shield (a) is shown with the beam-forming collimator insert (b) in place. The ion chamber (c) traverses a plane under computer control to map the dose in the plastic phantom (d) containing tissue-equivalent liquid. The laser beam (e) is used for alignment of the equipment with respect to the beam axis.

dose distribution in the patient by use of sequential treatments with several fields, to obtain the desired result by superposition. The data on the available neutron beams are provided in an atlas of full-scale isodose distributions. Many of these distributions are required to characterize the variety of field sizes, with and without field-shaping wedges, for the several source-to-skin distances (SSDs) used at MANTA for treating patients. Initially, the required dose distributions were obtained by measuring the neutron fields in a tissue-equivalent (TE) liquid phantom. This was accomplished by means of an automated, computer-controlled system (Figure 14) that maps the dose in a Cartesian grid system. The measured dose data were stored and later analyzed by an interpolation technique to provide the required isodose curves on a

computer-driven plotter. However, measurements to develop an individual dose distribution took several hours of beam time, so that this approach required inordinate amounts of measurement time to develop and expand the required atlas of isodose curves. Hence, NRL has developed a computer-based system to calculate the isodose curves required when new collimators or wedges are introduced. In this approach, only a few bench-mark measurements are needed to verify the computer program.

The model used in the dose distribution calculations is an extension of techniques used for conventional x-ray calculations. The dose at a point in the TE phantom is divided into two components: a primary component due to radiation arriving directly from the source without scatter by the phantom, and a scatter

component due to radiation scattered from elsewhere in the phantom. The dose at any designated point then is the sum of the primary and scatter components determined by numerical integration. The virtue of this method is that one can measure the dose along the central axis for a small number of circular fields and then derive the primary component as a function of depth and the scatter component as a function of depth and field size. This derivation is based on the principle that, in the limit of zero-field size, all of the radiation reaching a point on the axis is primary, since the infinitesimally small beam does not illuminate any off-axis volume to produce scattered radiation. As the field size is allowed to increase from zero, the dose deposited at the point will also increase due to scatter from an increasing volume of the phantom. Using the central-axis-depth dose data for a number of circular fields, one can extrapolate to zero-field radius and obtain the primary component as a function of depth. With the primary component in hand, the scatter contribution can also be determined. The method outlined does not strictly apply to the situation encountered in neutron radiotherapy because the forward peaking of the deuteron-on-beryllium reaction causes nonuniform neutron illumination of the front face of the phantom. This means that the correct scatter components cannot be simply derived from the measurements. However, NRL has developed a novel unfolding technique to circumvent this difficulty and obtain the correct scatter components.

The dose at any point P in the TE phantom can now be calculated as the summation of primary and scatter contributions to dose. The

calculation of scatter contribution is illustrated in Figure 15 for a rectangular field at depth Z in the phantom. The scatter contribution to dose is obtained by summing the contributions from all wedge-shaped sectors; that is,

$$S[R(\theta_i), Z] \frac{\Delta\theta}{2\pi},$$

where $S[R(\theta_i), Z]$ is the scatter function for a circular field of radius $R(\theta_i)$. However, since the neutron radiotherapy beam has an angular distribution, it is necessary to sum the scatter contributions using the differential elements indicated in Figure 15. Then the scatter contribution to the dose at P is given by

$$\sum_{i=1}^N \sum_{j=1}^{R_{\max}(\theta_i)} G[R_j(\theta_i), \theta_i] [S(R_{j+1}, Z) - S(R_j, Z)] \frac{\Delta\theta}{2\pi}.$$

Here, $G[R_j(\theta_i), \theta_i]$ takes into account the variation in intensity across each sector, and the second term is the scatter from each differential element. A dose matrix, equivalent to that obtained by mapping, is calculated for each depth Z .

The measured and calculated dose distributions are given for an open field (produced by a collimator alone) in Figure 16(a), and for a wedged field (produced by collimator and Teflon® wedge) in Figure 16(b). The agreement is quite satisfactory and is almost as good as the reproducibility of the measurements.

In summary, a computer-based model has been developed to generate dose distributions for the NRL-MANTA neutron radiotherapy beam. This model requires only a small number of measurements to provide a data

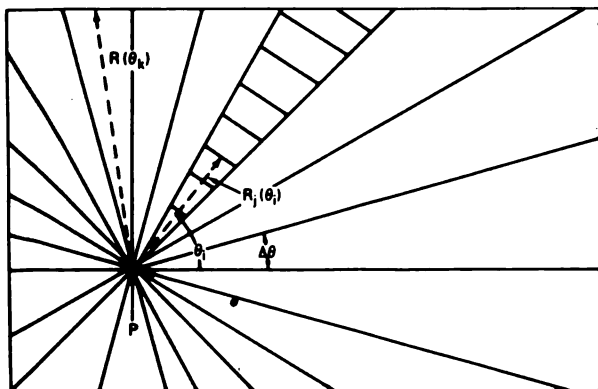


Figure 15. Geometry of scatter calculation. The scatter contribution to the point P is the sum of the contributions from the wedge-shaped sectors. In the idealized case, where the neutron beam has a uniform angular distribution, the contributions from the total sectors are summed, as from the sector labeled $R(\theta_i)$. When the angular distribution is taken into account, the contributions from the differential elements are summed as indicated in the sector labeled with the $R_j(\theta_i)$ differential element.

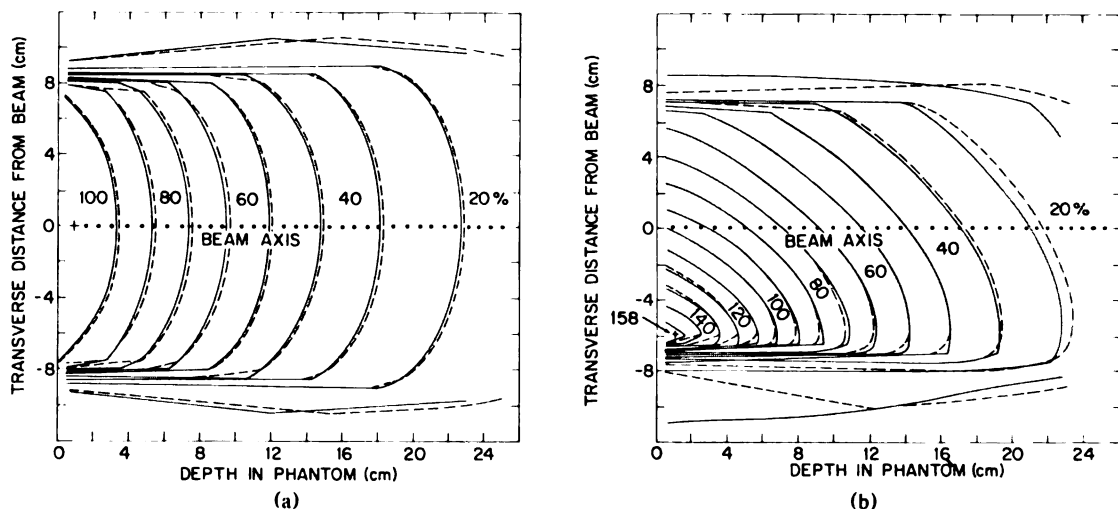


Figure 16 Calculated (dashed lines) and measured (solid lines) isodose distributions for (a) a nominal 15-cm $\times$ 15-cm field and (b) a nominal 12-cm $\times$ 12-cm field with a 45° wedge. SSD = 125 cm in both.

base and is effective for the variety of fields, open and wedged, at the various SSDs used for neutron radiotherapy. It has reduced the need to measure a large variety of fields for treatment planning to a few selected bench-mark

measurements to verify the calculations. The calculated isodose distributions have been incorporated in the standard atlas and are used daily for treatment planning.

[Sponsored by National Cancer Institute]

RECOGNITION

HONORS, AWARDS, AND TRAINING

HONORS AND INCENTIVE AWARDS

During 1978 NRL staff members earned 1781 awards under the Federal Incentive Awards program. These awards are summarized in the following table.

Distribution of Federal Incentive Awards During 1978

Navy Superior Civilian Service Award	6
Navy Meritorious Civilian Service Award	7
Award of Merit for Group Achievement	5
NRL E. O. Hulburt Annual Science Award	1
Outstanding Performance Ratings	322
Special Achievement Awards	122
Quality Salary Increases	186
Research Publication Awards	93
Invention and Patent Disclosures	228
Employee Suggestions	7
Length of Service Awards	653
Safety Certificates	135
Blood Donor Certificates	10
Commanding Officer's Award for Achievement in EEO	1
Commanding Officer's Award	5
TOTAL	1781

In addition, Laboratory employees received numerous scientific medals, military service awards, academic honors, and other forms of recognition, including election and appointment to offices in technical societies. The following is an alphabetical list of the persons receiving such recognition in 1978.

S. Ahn: *Vice President of Korean Scientists and Engineers Association in America, Inc., Washington Metro Chapter*

G.W. Anderson: *Member, Professional Advisory Board of Washington, D.C., Area Chapter, Epilepsy Foundation of America*

J.-D.F. Bartoe: *Selected for Payload Specialist Crew of Spacelab 2; member Investigators Working Group, Spacelab 2*

W.D. Bascom: *Detailed to ONR-London as Liaison Scientist*

C.D. Beachem: *Member of Handbook Committee, American Society for Metals*

L.S. Birks: *Appointed to Advisory Committee for Analytical Chemistry, American Chemical Society*

S.G. Bishop: *Member, Organizing Committee for the 8th International Conference on Amorphous and Liquid Semiconductors*



Dr. John-David Bartoe (left) and Dr. Dianne Prinz, NRL space scientists, have been selected as two of four payload specialist scientists for a 1981 mission of Spacelab 2. Mrs. Prinz is the first American woman to be assigned to such a crew and later could be chosen to fly on the Space Shuttle that will carry Spacelab into Earth orbit. The two scientists are shown with the High-Resolution Telescope and Spectrograph, one of the instruments to be used on their mission.

- R.J. Bobber:** *Appointed alternate U.S. delegate to the Electroacoustics Committee of the International Electrotechnical Committee*
- R.O. Bondelid:** *Member of Program Committee and Session Chairman for 8th International Conference on Cyclotrons and Their Applications (Bloomington, Ind.)*
- D.L. Book:** *Served as Chairman of the Nominations Committee of the American Physical Society (APS), Plasma Physics Division; elected member of the Executive Committee of the Plasma Physics Division, APS*
- J.P. Boris:** *Appointed to new Chair of Science in Computational Physics at NRL; Washington Academy of Science Award in Mathematics and Computational Sciences*
- A. Brodzinsky:** *Vice President, Administrative Committee of Components, Hybrids and Manufacturing Technology Society, IEEE*
- G.E. Brueckner:** *E.O. Hulburt Science Award; member Organizing Committee, International Astronomical Union (IAU) Commission 12; member Organizing Committee Joint IAU discussion on "Physics of the Chromosphere Corona-Wind Complex and Mass-Loss in Stellar Atmospheres"; member Investigators Working Group, Shuttle Orbital Flight Test 4; member Investigators Working Group Spacelab 2*
- J.A. Bucaro:** *Fellow, Acoustical Society of America*
- J.D. Bultman:** *Appointed by the Association for Tropical Biology to associate editorship of the journal Biotropica*
- J.W. Butler:** *Coauthor of best Navy contribution to the Basic Research Session of the Navy/Air Force Science and Engineering Symposium*
- F.J. Campbell:** *Appointed to Board of Directors, Conference on Electrical Insulation and Dielectric Phenomena, National Research Council; elected to Administrative Committee of the Electrical Insulation Society, IEEE*
- H.W. Carhart:** *Chairman, International Symposium on Grain Elevator Explosions, National Academy of Sciences*
- A. Christou:** *Organizer of Workshop on "Microelectronics with Special Emphasis on Surface Analytical Techniques," for Scanning Electron Microscope (SEM) Symposium 1979 (sponsored by Illinois Institute of Technology, Research Institute (IITRI), SEM, Inc.; advisor to SEM symposium on "Advances in Electron Optics"; advisor to "Semiconductor Packaging Sessions" at International Microelectronics Conference (sponsored by ITTRI), Anaheim, Calif.; organizer of First Athens Conference on Electron Microscopy (cosponsored by European Electron Microscopy Society), Athens, Greece*
- T.A. Chubb:** *Navy Distinguished Civilian Service Award*
- J.R. Clement:** *Navy Meritorious Civilian Service Award*
- E.D. Cohen:** *Member of (1) Standards Committee on Microwave Transistor Characterization, (2) Microwave Devices Technical Committee of the Electron Device Society, (3) 1979 International Solid State Circuits Conference Technical Program Committee, and (4) MIT-7 Microwave Theory and Techniques Society Committee for Microwave and Millimeter Wave Devices—all of IEEE; deputy Navy member of Working Group A, Office of Under Secretary of Defense (R&E) Advisory Group on Electron Devices*
- D.C. Cook:** *Member of Nuclear Instruments and Detectors Committee, IEEE Nuclear and Plasma Sciences Society; Secretary of ANSI Committee N42 (Nuclear Instrumentation); Chief U.S. Delegate to Subcommittee 45B (Radiation Protection Instrumentation) and U.S. Delegate to Technical Committee 45 (Radiation Instrumentation) of the International Electrotechnical Commission; member of the Program Committee and Treasurer of the IEEE 1978 Nuclear Science Symposium*
- L.A. Cosby:** *Appointed member of Defense Science Board on Counter Communications, Command and Control Task Force*
- R.F. Cozzens:** *Chairman, Gordon Research Conference on "Photoconductors"; lecturer, Summer Institute in Science and Technology, State University of New York at New Paltz; Service Award, Chemical Society of Washington*
- T.W. Crooker:** *Elected to Executive Committee of Materials Division of the American Society of Mechanical Engineers; appointed Chairman of American Society for Testing and Materials Task Group E24.04.05 on Fatigue Crack Growth Rate Testing in Aqueous Environments; appointed Secretary of Metals Properties Council Task Group on Corrosion*



Dr. Talbot A. Chubb (center), Head of the Upper Air Physics Branch, Space Science Division, receives the Navy Distinguished Service Award from the Honorable David E. Mann, Assistant Secretary of the Navy. Mrs. Chubb shared the proud moment when the Navy recognized her husband's outstanding work in upper atmosphere, solar, and space research and in developing the SOLCHEM solar energy system.

Fatigue; appointed member of Federal Highway Administration Panel on Corrosion Fatigue Characteristics of Bridge Steels

W.H. Cullen: *Chairman, Design Engineering Conference Symposium, "Modern Methods of Failure Analysis"*

J.E. Davey: *Associate member of Main Group and of Low Power Working Group, OUSDR&E Advisory Group on Electron Devices; Chairman, Ad Hoc Committee on GaAs Device Reliability, NATO AC-243 Panel III*

K.L. Davis: *Secretary-Treasurer, IEEE Washington-Baltimore-Northern Virginia Chapter of Sonics and Ultrasonics Group*

A.P. DeFonzo: *Member of Technical Review Committee, Source Selection Committee, Department of Energy Photovoltaics Request for Proposals for FY 79 and 80 Research Program; Energy, Solar Energy Research Institute, Measurements Conference; Solar Energy Research Institute Amorphous Workshop Cochairman, DARPA Workshop on Optical Control of Microwaves*

R.A. De Marco: *Elected alternate councilor for the American Chemical Society (ACS) from the Chemical Society of Washington; elected to the Executive Board of the Fluorine Division of the ACS; appointed Audit Chairman for Fluorine Division of ACS*

sion of the ACS; appointed Audit Chairman for Fluorine Division of ACS

J.A. DeSanto: *Appointed to Commission on Underwater Acoustics, Acoustical Society of America*

J.K. Dixon: *Appointed member of the Artificial Intelligence Committee of the IEEE Special Interest Group on Systems, Man, and Cybernetics*

A. Eller: *Elected Senior Member of IEEE; Technical Program Chairman for the OCEANS 78 Conference (Washington, D.C.)*

R.C. Elton: *President of NRL Chapter of Sigma Xi, The Scientific Research Society of America; Program Committee, 2nd International Conference on Atomic Processes in Plasmas; Program Committee, 10th International Quantum Electronics Conference*

B.J. Faraday: *Appointed Chairman of the Scientific and Engineering Program Committee, NRL*

L. Flax: *Fellow, Acoustical Society of America*

J.L. Flippen-Anderson: *Chairperson, Crystallographic Data Committee, American Crystallographic Association*

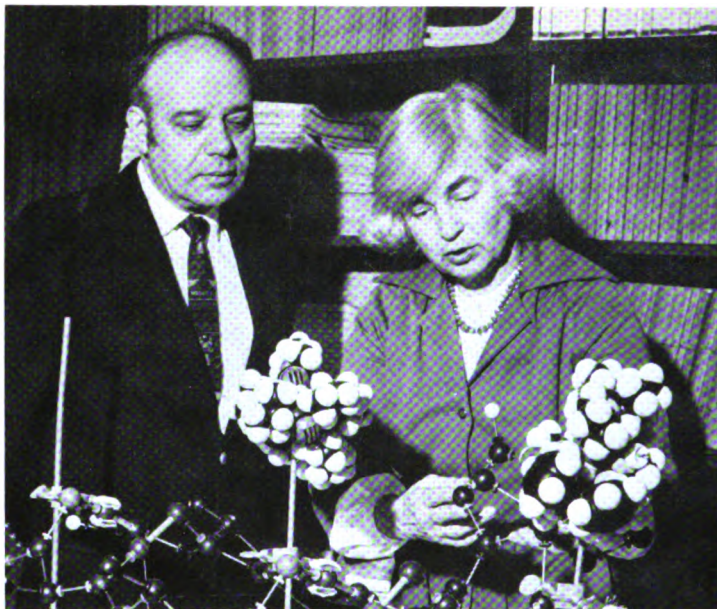
R.B. Fox: *Appointed member of following committees of the American Chemical Society:*

- Chemical Abstracts Service; Nomenclature; Chairman, Subcommittee on Society Committees and Commissions, A.D. Little Task Force; liaison to Science Commission and to Committee on Budget and Finance; subcommittees on Human Rights, Problems and on Organization of Meeting of Chemical Society Presidents; International Activities Committee; Divisional Committee on Polymer Nomenclature; Secretary of Commission on Macromolecular Nomenclature, International Union of Pure and Applied Chemistry*
- W.B. Fox: *Elected Chairman of American Chemical Society's Division of Fluorine Chemistry; appointed to NATO Advanced Research Institute for Molecular Metals; member of Navy Steering Committee for Protective Respiratory Device Development; appointed to Navy Committee on Advanced Polymers*
- E.J. Friebele: *Editorial Chairman, Glass Division, American Ceramic Society*
- H. Friedman: *NASA Exceptional Scientific Achievement Medal; invited participant to Senate Subcommittee on Science, Technology, and Space hearing on the Future of Space Science and Space Applications; invited lecturer at Explorer I Anniversary Symposium, National Academy of Sciences; Chairman, High Energy Astrophysics Division, American Astronomical Society*
- M.J. Fritts: *Appointed NRL representative of the Ad Hoc Committee on Numerical Hydrodynamics for SEAHAC (Naval Sea Systems Hydromechanics Committee)*
- W.D. Garrett: *Member of United Nations' Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP); Chairman, GESAMP Working Group on Interchange of Pollutants Between the Atmosphere and the Oceans; member of Committee on Air-Sea Interactions; American Meteorological Society; named U.S. member of Joint United Nations Group on Marine Pollution Monitoring Sponsored by the Intergovernmental Oceanographic Commission of UNESCO and the World Meteorological Organization*
- R.D. Gilardi: *Chairman, Publications Committee, American Crystallographic Association*
- J.V. Gilfrich: *Corresponding editor of X-Ray Fluorescence Spectrometry, an abstract journal, London*
- R.J. Goode: *Session chairman, "5A-Fatigue Crack Growth (Residual Stresses, Closure, etc.)," 11th National Symposium on Fracture Mechanics, Blacksburg, Va.*
- J.M. Goodman: *Chairman, 1978 International Symposium on the Effect of the Ionosphere on Space and Terrestrial Systems (IES '78); member, Working Group E1 (Ionosphere-Reflected Propagation Predictions) of the Solar Terrestrial Predictions/Proceedings and Workshop (ISTP/P-W)*
- V.L. Granatstein: *Member of the Scientific Committee, 2nd International Conference on Energy Storage, Compression and Switching, Venice, Italy; consultant to Concept Review Committee, Office of Fusion Energy, Department of Energy*
- R.E. Greene: *Chairman of Steering Committee, Tri-Service Cathode Workshop; editorial board, Applications of Surface Science*
- D. Greenwalt: *Reappointed to Commission on Budget and Finance, American Geophysical Union*
- O.M. Griffin: *Member of Committee on Heat Transfer in Energy Systems, American Society of Mechanical Engineers (ASME); appointed associated editor of the Journal of Fluids Engineering, Transactions of ASME*
- J.R. Griffith: *Alternate Councilor and member of the Executive Committee, Organic Coatings and Plastics Division, American Chemical Society*
- I.D. Groves: *Appointed member of the Technical Committee on Engineering Acoustics, Acoustical Society of America (ASA); Treasurer, Florida Chapter of ASA*
- D.U. Gubser: *Selected member of Interagency Advanced Power Group*
- G.A. Haas: *Chairman, 1978 Tri-Service Cathode Workshop*
- L.M. Hammarstrom: *Navy Superior Civilian Service Award*
- R.J. Hansen: *Chairman, Ad Hoc Committee on Drag Reduction, Naval Sea Systems Command Hydromechanics Committee*
- J.R. Hawthorne: *Elected Vice Chairman, Committee E-10 on Nuclear Applications and Measurements of Radiation Effects, American Society for Testing and Materials*
- R.N. Hazlett: *Chairman and organizer, NAVAIR-NRL Workshop on Basic Research*



Soon after becoming Commanding Officer of NRL, Capt. E. E. Henifin (right) received a Gold Star representing a second Meritorious Service Medal for his outstanding service as Deputy Director of Navy Technology. RADM A. J. Baciocco, Jr., Chief of Naval Research, congratulates the Captain on his honor.

- Needs for Synthetic Hydrocarbon Jet Aircraft Fuels; Chairman, Basic Research Working Group, NASA Workshop on Jet Fuel Thermal Stability*
- W.A. Hendrickson:** *Arthur S. Flemming Award; Navy Meritorious Civilian Service Award*
- E.E. Henifin:** *Meritorious Service Medal (gold star in lieu of second medal)*
- J.K. Hirvonen:** *Member of Committee on Ion Implantation and Competing New Surface Treatment Technologies, National Materials Advisory Board, Commission on Sociotechnical Systems, National Research Council; best Navy contribution to the Basic Research Session of the Navy/Air Force Science and Engineering Symposium*
- D.L. Hunston:** *Chairman of the Committee on Education, Society of Rheology*
- C. Hurdle:** *Appointed associate editor, U.S. Navy Journal of Underwater Acoustics; Cochairman, Session Q, Joint Meeting, Acoustical Society of America (ASA) and Acoustical Society of Japan (Honolulu, Hawaii); appointed member of the Membership Committee, ASA*
- K.J. Johnston:** *Chairman, Working Group for Commission 24 of International Astronomical Union on the Identification of Compact Radiol/Optical Sources*
- W.W. Jones:** *Member of Review and Program Committee for the 2nd International Symposium on Gas Flow and Chemical Lasers, Rhode-Saint-Genese, Belgium*
- M.N. Kabler:** *Appointed to Steering Committee, 1981 International Conference on Defects in Insulating Crystals*
- I.L. Karle:** *Elected to National Academy of Sciences; appointed to the Advisory Board, Office of Chemistry and Chemical Technology, National Research Council, nominating committee for officers of the American Crystallographic Association; alternate delegate to the International Union of Crystallography (Warsaw); Abby Rockefeller Mauzé Visiting Lecturer at MIT; lecturer at International School for Crystallography (Erice, Italy); Honorary Chairman of Symposium on Organic Crystal Chemistry (Dymaczewo, Poland); biography in Encyclopedia of Science and Technology (McGraw-Hill); panel*



Drs. Jerome and Isabella Karle of the Laboratory for Structure of Matter have worked together at NRL since the late 1940s and have won numerous honors for their researches into the structure of crystals and other materials. In 1978 Mrs. Karle became the first chemist of her sex to be elected into the National Academy of Sciences. The Karles are shown inspecting models of peptide molecules.

member for choosing recipients of national scientific awards

- J. Karle:** *Elected member of Executive Committee, International Union of Crystallography (IUCr); elected representative of IUCr on European Crystallographic Committee; appointed member of Calendar Subcommittee of IUCr; appointed member of Committee on Chemistry and Federal Policy of National Academy of Sciences (NAS); elected delegate representing NAS at 11th Assembly of IUCr in Warsaw; appointed member of organizing committee for joint meeting with Japanese Crystallographic Society on Modulated Structures; plenary lecturer at Symposium on Chemical Crystallography at Dymaczewo, Poland; guest lecturer at Symposium on Non-crystalline Substances in Pécs, Hungary*
- C.A. Kennedy:** *Commendation from the Secretary of the Navy for efforts with NRL Amateur Radio Club in providing communications during flood of July 1977 in Johnstown, Pa.*
- P.H. Klein:** *Member, Materials Processing Panel, NASA Space and Terrestrial Applications Steering Committee; NASA Supporting Research and Technology Advisory Subcommittee*

N.C. Koon: *President, Greater Washington Solid State Physics Colloquium Committee*

J.M. Krafft: *Appointed Technical Editor, Transactions of ASME, Journal of Engineering Materials and Technology; member of Marine Board Panel on Verification Guidelines for Offshore Structures*

J.J. Krebs: *Elected Secretary, NRL Chapter of Sigma Xi*

F.K. Lepple: *Appointed to Advisory Board of the College of Marine Studies, University of Delaware*

H. Lessoff: *President NRL Chapter of Sigma Xi; member, Electronic Materials Committee of the American Institute of Mining, Metallurgical and Petroleum Engineers; liaison representative, National Materials Advisory Board of the National Academy of Sciences; Session Chairman, 7th International Conference on GaAs and Related Compounds; Session Chairman, Gordon Conference on Crystal Growth*

M.C. Lin: *1978 Pure Science Award, NRL Chapter of Sigma Xi, the Research Society of North America*

T.P. Lindgren: *Associate member of Working Group A, Advisory Group on Electron Devices*

- R.C. Little: *Navy Meritorious Civilian Service Award*
- F.J. Loss: *Elected Secretary, International Cyclic Crack Growth Rate Group; elected Secretary, Committee E-24.08 on Elastic-Plastic and Fully Plastic Fracture Mechanics Technology, American Society for Testing and Materials*
- C.L. Marquardt: *Secretary, Greater Washington Solid State Physics Colloquium*
- G.E. Matthews: *Commendation from the Secretary of the Navy for efforts with NRL Amateur Radio Club in providing communication during the flood of July 1977 in Johnstown, Pa.*
- E. McCafferty: *Vice President and Program Chairman, National Capital Section of the Electrochemical Society (ES); member, Executive Committee, Corrosion Division of ES*
- B.D. McCombe: *Member, Navy Technical Review Committee, Joint Services Electronics Program; associate Navy member, Advisory Group on Electron Devices, Working Group B; member, Organizing and Program Committee, 6th Annual Conference on the Physics of Compound Semiconductor Interfaces; member of Program Committee and session chairman, International Conference on Solids and Plasmas in High Magnetic Fields; member, Board of Editorial Associates, Semiconductors and Insulators; member of National Science Foundation's Advisory Committee for Materials Research, National Magnet Laboratory Visiting Committee; Chairman of Facilities Subcommittee, National Research Council Panel on High Magnetic Field Research and Facilities; Adjunct Professor of Physics, State University of New York at Buffalo*
- W.J. McDonough: *Chairman, Baltimore-Washington Section, American Ceramic Society*
- E.A. McLean: *Executive Committee member of the Plasma Science and Applications Committee of the Nuclear and Plasma Science Society, IEEE*
- J.J. Mecholsky: *Chairman, American Society for Testing and Materials (ASTM) Subcommittee (E24.07) Task Group on Fractography; Secretary, ASTM Subcommittee on Brittle Materials (E24.07)*
- D.J. Michel: *Vice Chairman, Nuclear Metallurgy Committee of American Society of Mechanical Engineers and American Society for Metals; National Capital Award for Professional Achievement in Engineering, D.C. Council of Engineering and Architectural Societies; member of Technical Program Committee for First Topical Meeting on Fusion Reactor Materials*
- J.B. Milstein: *Member, Organizing Committee, 1978 Summer Symposium on Solid State Chemistry, and editor of the symposium proceedings*
- W.B. Moniz: *Vice President, NRL Chapter of Sigma Xi, the Scientific Research Society of North America; Chairman, Navy Polymer Characterization Meeting (sponsored by Navy Council on Materials and Structures)*
- D.R. Mulville: *Program organizer and coeditor of the Proceedings of the ONR Symposium on Fracture Mechanics; appointed to editorial board of The Composites Technology Review*
- R.E. Neidert: *Appointed member of Finance Committee, 1980 IEEE International Microwave Symposium*
- W.G. Neubauer: *Fellow, Acoustical Society of America*
- M. Nisenoff: *Session Chairman, Applied Superconductivity Conference (Pittsburgh)*
- L.M. Noel: *Legion of Merit*
- S.L. Ossakow: *Appointed associate editor of the Journal of Geophysical Research, Space Physics Section (for 3 years); selected to write the U.S. National Committee's 1975-1978 Quadrennial Report on Ionospheric Irregularities for the International Union of Geodesy and Geophysics*
- E.D. Palik: *Invited Lecturer for NATO Advanced Summer Institute on Nondestructive Characterization of Semiconductor Materials and Devices*
- L. Palkuti: *Newsletter Editor and Associate Transactions Editor of the IEEE Society on Components, Hybrids and Manufacturing Technology; appointed to IEEE Council on Ocean Engineering*
- P.J. Palmadesso: *Union of International Radio Science (URSI) representative in the URSI-International Association of Geomagnetism and Aeronomy Working Group on Wave Instabilities in Space Plasmas*
- K. Papadopoulos: *Washington Academy of Science Award for Scientific Achievement in the*

- Physical Sciences 1978; member NASA Space Plasma Theory Panel; correspondent for "Comments on Plasma Physics"; Chairman, Gordon Conference on Space Plasmas*
- R.K. Parker:** *Member of High-Power Microwave Panel of DDR&E Particle Beam Technology Study Group*
- W.L. Phillips:** *Member of Composite Materials Committee of American Institute of Mining, Metallurgical and Petroleum Engineers*
- W.C. Plant:** *Elected to Commission F (Wave Phenomena in Nonionized Media) of URSI (International Union for Radio Science)*
- D.K. Prinz:** *Selected for Payload Specialist Crew of Spacelab 2; member of Investigators Working Group, Spacelab 2*
- H. Rabin:** *Member, Naval Studies Board Panel on the Implications of Future Space Systems on the U.S. Navy, sponsored by the National Research Council, National Academy of Sciences*
- J.F. Reintjes:** *Member of the Program Committee of the First International Conference on Picosecond Phenomena*
- M.L. Reuss, Jr.:** *Waveguide Standards Committee of IEEE Microwave Theory and Techniques Society; Subcommittee on Nonlinear and Active Waveguide Components (457)*
- R.W. Rice:** *Navy Meritorious Civilian Service Award; Vice Chairman, Basic Science Division, American Ceramic Society; Cochairman, International Conference on Science of Machining and Surface Finishing Ceramics*
- P.B. Richards:** *Member of Executive Committee and Board of Directors, American Astronautical Society*
- B.H. Ripin:** *Elected to the IEEE Nuclear and Plasma Science Society Executive Committee of the Plasma Science Applications Committee; organized and edited an IEEE minicourse on "Modern Plasma Diagnostics" (Monterey, Calif.)*
- P.H. Rogers:** *Vice President, Florida Chapter of Acoustical Society of America*
- F.E. Saalfeld:** *Elected member of Executive Committee, Chemical Society of Washington; appointed Chairman of Chemical Society of Washington Long-Range Planning Committee*
- S.C. Sanday:** *Member of the Structures and Dynamics Committee of the Gas Turbine Division, American Society of Mechanical Engineers*
- R.J. Sanford:** *Vice Chairman of Committee on Optical Methods, Society for Experimental Stress Analysis (SESA); member of Monograph Committee, SESA*
- J.T. Schriempf:** *Chairman, Vulnerability, Effects and Hardening Panel of the High Energy Laser Review Group*
- J.W. Schwartz:** *Appointed Membership Chairman, Commission C, U.S. National Committee of the International Union of Radio Science (URSI)*
- P.R. Schwartz:** *Participated in summer study on "Upper Atmosphere Research in the 1980's," sponsored by the Committee on Solar-Terrestrial Research, Geophysics Research Board of National Academy of Sciences-National Research Council*
- M. Shapiro:** *Member, Committee of Honor of the Academia dei Lincei (Rome) for Celebration of the Einstein Centennial and invited contributing author to the commemorative volume; Medal of Honor, Société d'Encouragement au Progrès, Paris; Director, International School of Cosmic-Ray Astrophysics, Erice, Sicily; member American Physical Society (APS) Publications Committee; associate editor of Physical Review Letters (publ. by APS); member, Executive Committee, Division of High-Energy Astrophysics, American Astronomical Society; member, Executive Board, Texas Symposia on Relativistic Astrophysics; Senior correspondent and member of the Scientific Advisory Board, Ettore Majorana Center for Scientific Culture; member, Scientific Advisory Board for a European University of Pure Science and a Mediterranean Polytechnic Institute; member, Steering Committee, Deep Underwater Muons and Neutrino Detection Consortium*
- J.P. Shelton:** *Member, Administrative Committee of Antennas and Propagation Society (AP-S) of IEEE; IEEE AP-S International Symposium Technical Program Committee*
- G.H. Sigel:** *1978 Sigma Xi Applied Science Award; Chairman of Tri-Service Committee on Radiation Effects in Optical Fibers; member of Research Committee of Glass Division of American Ceramic Society; member of Organizing Committee of 1978 Conference on the Physics of SiO₂ and Its Interfaces; member of International Advisory*



Dr. Maurice M. Shapiro, Chief Scientist of the Laboratory for Cosmic Ray Physics, received a Medal of Honor from the Société d'Encouragement au Progrès for his notable work in high-energy physics and cosmic rays.

- Board for Conference on Electrical, Magnetic and Optical Properties of Glasses*
- R. Silberberg: *Assistant Director, International School of Cosmic Ray Astrophysics, Erice, Sicily*
- E.F. Skelton: *Requested by Office of Under Secretary of Defense (R&E) via ONR to review the field of high-pressure science and technology in Japan*
- R.A. Skop: *Board of Editors, The Shock and Vibration Digest*
- J. Solash: *Organizer, NAVAIR-NRL Workshop on Basic Research Needs for Synthetic Hydrocarbon Jet Aircraft Fuels*
- B.E. Spielman: *Elected member IEEE Administrative Committee for Microwave Theory and Techniques Society (MTT-S); appointed Secretary for IEEE 1980 International Microwave Symposium; appointed member IEEE/MTT-S Technical Committee on Microwave Integrated Circuits*
- D.S. Spicer: *Member of Subcommittee for Study of Energy Release in Flares, International Council of Scientific Unions; preparing a major review of the status of Solar Flare Observations and Theory at the request of NASA and the European Space Administration; Chairman and organizer of Solar Physics Workshop on Solar flares for Solar Physics Division of American Astronomical Society*
- J.A. Sprague: *Chairman, 9th International Symposium on Effects of Radiation on Structural Materials*
- G.L. Stamm: *Chairman, Joint Infrared Standards Working Group*
- R.L. Statler: *Navy representative to the Solar Working Group, Interagency Advanced Power Group; Steering Committee for 13th IEEE Photovoltaic Specialists Conference*
- L.E. Steele: *Award of Merit, American Society for Testing and Materials (ASTM); elected Fellow, ASTM*
- R.T. Swim: *Member, NAVMAT Ocean Engineering Exploratory Development Strategy Team*
- H.H. Szu: *Member of Princeton Institute for Advanced Study (Princeton, N. J.)*
- P.C. Taylor: *Member, Program Committee for the 8th International Conference on Amorphous and Liquid Semiconductors*
- R.E. Thomas: *Chairman, Test and Evaluation Committee, Tri-Service Cathode Workshop*
- R.J. Timme: *Invited speaker at international colloquium sponsored by Centre Nationale de Recherche Scientifique, on "Physics of Metallic Rare Earths," St. Pierre de Chartreuse, France*
- D.D. Triantos: *Arranged a symposium on the Communication Network of the Future, American Association for the Advancement of Science*
- P.J. Turchi: *Member, Navy Pulsed Power Technical Advisory Group; member, Air Force Panel on Education in Pulsed Power*
- G.R. Valenzuela: *Invited to NATO Advanced Study Institute meeting on "Surveillance of Environmental Pollution and Resources by Electromagnetic Waves" (Nord-Torpa, Norway) to present paper; Inter-Union Commission on Radio Meteorology 1978-1981; appointed U.S. Delegate to 19th International*

RECOGNITION

Union for Radio Science General Assembly (Helsinki, Finland) and invited to present a paper and an oral report

N.R. Vanderplaats: *Member of subcommittee on Terms for Nonlinear and Active Waveguide Components, Waveguide Standards Committee of the IEEE Microwave Theory and Techniques Society*

M.E. Van Hoosier: *Member, Investigators Working Group, Shuttle Orbital Flight Test 2; member of Investigators Working Group, Spacelab 2*

D.L. Venezky: *Elected Councilor to the American Chemical Society (ACS) from the Chemical Society of Washington (CSW); appointed Chairman of Membership Activities Committee, CSW; appointed Chairman of the Annual Reports, Academically Oriented Sections Subcommittee and New Section Formation Subcommittee. ACS Council Committee on Local Section Activities, Charles L. Gordon Memorial Award for Service to CSW; Chairman, Task Group on Methods for the Analysis of Chelants, American Society for Testing and Materials, Subcommittee D19.06 (Organics in Water)*

C. Vittoria: *Member, Program Committee for 1978 Conference on Magnetism and Magnetic Materials; member, IEEE Selection Committee for Invited Speakers to Conferences; invited speaker at International Conference on Magnetism, Florence, Italy*

W.S. Watt: *Appointed associate editor of the IEEE Journal of Quantum Electronics; Chairman of the NATO Exploratory Group on Laser Technology for Military Applications*

D.C. Webb: *Associate member of Working Group A, Advisory Group on Electron Devices; Vice Chairman, IEEE Washington-Baltimore-Northern Virginia Chapter of Sonics and Ultrasonics (SU) Group; IEEE SU Symposium Program Committee*

R.J. Weimer: *Vice Chairman of Subcommittee on Fracture of Composites, Society for Experimental Stress Analysis*

E.P. Westbrook: *Commendation from the Secretary of the Navy for efforts with NRL Amateur Radio Club in providing communication during the flood of July 1977 in Johnstown, Pa.*

L.R. Whicker: *Navy member of Working Group A, Advisory Group on Electron Devices; Chairman of Technical Task Group I, U.S.-NATO Expert Control; U.S. program member, Advisory Group for Aerospace R&D, Millimeter Wave Conference; Professional Activity Coordinator for Division IV, IEEE; ex officio member (past president) of Microwave Theory and Techniques Society, IEEE; appointed General Chairman, 1980 International Microwave Symposium*

F.W. Williams: *Appointed member and on Steering Committee, National Ad Hoc Committee of Fire Modeling*

H.A. Willing: *Appointed Chairman of Finance Committee, IEEE 1980 International Microwave Symposium*

S.A. Wolf: *Program cochairman and editor (with three others) of Proceedings of Conference on Future Trends in Superconducting Electronics*

John Otto, Head of the Photographic Branch, (right) and Capt Noel (next to him) are shown in Las Vegas, Nev., receiving the 1978 Industrial Photographic Department of the Year Award for Nonprofit Organizations. An Eastman Kodak Co. representative (left) and the Chairman of the Professional Photographers of America Industrial Division are presenting a model of a lens system, which is now displayed in Building 222.



I. Wolock: *Chairman, Technical Standing Committee on Composites, Navy Council on Materials and Structures; session chairman, 2nd International Conference on Composite Materials*

HEAO-1 Large-Area X-Ray Survey Experiment Team, *Headed by E.T. Byram: NASA Group Achievement Award*

Mercury Contamination Control Team: *Award of Merit for Group Achievement for work on the CBD water system*

Photographic Branch, Technical Information Division: *1978 Industrial Photographic Department of the Year Award for nonprofit organizations*

RESEARCH PUBLICATION AWARDS

Each year the Director of Research presents cash awards and certificates to the authors of the best NRL scientific or technical papers of the year. This practice was established in 1968 by Dr. Alan Berman, Director of Research, as a means of encouraging and rewarding outstanding scientific writing by the Laboratory staff. Committees for each of 16 major research units nominated a total of 213 papers that were published in 1978; 41 of these ultimately earned Research Publication Awards. Each of the divisions was permitted \$600, which in some cases went to 2 authors, in another was shared by 14 authors, and in the other divisions went to varying numbers of authors in between these extremes. The Office of the Director of Research awarded a smaller sum, and an extra prize was presented to the three authors of an NRL special report. On February 9, 1979, the awards were presented to the 93 NRL authors at the 11th Annual Research Publication Awards Dinner held at the Bolling Air Force Base Officers' Club. In addition to the check, each winner received a certificate and a bronze paperweight.

The unclassified winning papers are included in the following section under "Papers in Periodicals, Books, and Proceedings of Meetings" and are designated by daggers in the margin. NRL authors are listed below by their research units. There were five non-Laboratory coauthors, who are not named.

PUBLICATION AWARDS WINNERS

Office of the Director of Research (1001)

John H. Gardner, Jr.	Peter J. Palmadesso
Ronald Hirsch	Peter Rogers
Stephen Mellman	Jay W. Schwartz
Elaine Surick Oran	

Electronics Technology Division (5200)

James M. Ferrari	Pietro de Santis
George T. Rado	Carmine Vittoria
Christen Rauscher	Harry Alfred Willing

Radar Division (5300)

James J. Alter	Jules P. Letellier
James P. Hansen	Bernard L. Lewis
Dean D. Howard	James W. Titus
Frank F. Kretschmer, Jr.	

Optical Sciences Division (5500)

Robert H. Dixon	Bruce D. Evans
Terence Donohue	John F. Seely
Raymond C. Elton	Marlyn Stapelbroek

Tactical Electronic Warfare Division (5700)

John S. Baras	Leo W. Lemley
Marilyn L. Emmans	Stanley S. Leroy

Chemistry Division (6100)

Denis J. Bogan	Robert N. Hazlett
Jack C. Burnett	Jeffrey Solash
George H. Fielding	

Material Science and Technology Division (6300)

Laurence A. Cooley	Kuntimaddi Sadananda
Thomas W. Crooker	George R. Yoder

Radiation Technology Division (6600)

Larry L. Boyer	Dimitrios A. Papaconstantopoulos
Thomas A. Kennedy, Jr.	Neal D. Wilsey
Barry M. Klein	

Plasma Physics Division (6700)

James Gary Eden	Redge A. Mahaffey
Jeffrey Golden	Edward Ott
Abdul Wahab Kadir Ali	John A. Pasour
Christos A. Kapetanakis	Mark R. Schoeberl
Martin Lampe	Darrel F. Strobel



Christine Hoffman (left), Communications Sciences Division, receives an NRL Publications Award from Capt. L. M. Noel, Commanding Office of the Laboratory at the time of the Awards Dinner.

Space Science Division (7100)

J. David Bohlin
George A. Doschek
Uri Feldman
W. Neil Johnson
Kenneth J. Johnston

Robert L. Kinzer
James D. Kurfess
Gerald L. Mader
Neil R. Sheeley, Jr.

Ocean Sciences Division (8300)

James W. Fitzgerald Jack A.C. Kaiser

Ocean Technology Division (8400)

Alfred V. Clark, Jr. Steven E. Ramberg

Communications Sciences Division (7500)

Robert J. Dinger
Joseph A. Goldstein
Rodney W. Johnson

Edward J. Kennedy
John E. Shore

Space Systems Division (7900)

Lorenzo J. Abella
Walter W. Atkins
Jay R. Baker
Warren L. Bendel
James F. Diggs
Richard L. Eibert
Frederick Fine

Ronald J. Fiskum
Charles S. Guenzler
Jong-Sen Lee
Danny C. Lim
James C. Ritter
Dale L. Schuler
Richard L. Statler

Acoustics Division (8100)

Louis R. Dragonette
Lawrence Flax

Richard M. Heitmeyer
William B. Moseley

Underwater Sound Reference Detachment (8200)

Craig K. Brown
Allan C. Tims

Arnie Lee Van Buren

CONTINUING EDUCATION AND TRAINING

During 1978, members of the civilian staff participated in 2735 instances of education and training. The program was expanded by the establishment of the Individualized Learning Center where prerecorded courses and information packages are available at the convenience of individuals and small groups. The Center has four study carrels or booths equipped with small videotape players and four equipped to present slide sequences. Eleven college courses were videotaped in the classrooms of participating universities and sent week by week to the Center where they were studied by nearly 120 NRL employees.

The most common study procedure was for participants to work full time at the Laboratory and take job-related scientific courses at universities and schools in the Washington area. There were also the following formal programs, in which 105 persons were enrolled: Advanced Graduate Research, Edison

Memorial, Select Graduate, and Apprentice. In addition, there were 61 persons not on the NRL payroll who worked here during 1978 as postdoctoral Resident Research Associates.

The four postgraduate programs and the participation in 1978 are described in the remainder of this section.

Advanced Graduate Research Program

The Advanced Graduate Research Program, which was started in 1964, enables selected employees to devote full time to research or course work in their own or a related field for one academic year at an institution of their choice without the loss of regular salaries, leave, or fringe benefits. From the inception of the program through 1978, 121 employees have participated in this program. Criteria for eligibility include professional stature consistent with the applicant's opportunities and experience, a satisfactory program of study, and acceptance by the institution selected by the applicant. The program is open to midlevel (and above) employees who have completed 6 years of federal service, including 4 years at NRL.

The following are the NRL staff members who began their programs in the fall of 1978. The student's division and chosen institution enrolled are given following each name.

- Stephen Bishop (Electronics Technology),
Royal Signals and Radar Establishment,
Great Malvern, England
- Michael I. Haftell (Radiation Technology),
University of Graz, Graz, Austria
- William R. Hunter (Space Science), Imperial
College of Science and Technology, London
- Robert L. Kinger (Space Science), University
of California, San Diego
- Pay-June Lin-Chung (Electronics Technology),
Cavendish Laboratory, Cambridge, England
- David J. Nagel (Radiation Technology),
National Bureau of Standards, Gaithersburg,
Maryland
- Robert J. Sanford (Ocean Technology), University
of Maryland, College Park
- Neal D. Wilsey (Radiation Technology),
University of New York, Albany

Edison Memorial Graduate Training Program

This program enables employees to pursue advanced studies in their fields at local universities. Eligible employees who are selected for participation in this program normally spend 24 hours per week in their work at the Laboratory and 16 hours per week in their studies. The criteria for eligibility include a minimum of one year of service at NRL, a bachelor's or master's degree in an appropriate field, and professional standing in keeping with the candidate's opportunities and experience.

From 1963 through 1978, 130 employees have studied under the Edison Program. The following began study as Edison Scholars in 1978:

- William Goodell (Optical Sciences), George
Washington University
- Donald Kallgren (Communications Sciences),
University of Maryland
- Patricia Tatem (Chemistry), George Washington
University
- Ballard Troy (Space Science), George Washington
University
- Stephen Wales (Acoustics), Catholic University

Resident Research Associateships

Selected Resident Research Associates, who are not NRL employees, spend up to two years here pursuing postdoctoral training and research in their chosen fields under the guidance of NRL scientists. The responsibility for evaluating and selecting the best qualified applicants rests with the National Research Council of the National Academy of Sciences and the National Academy of Engineering. The 31 new postdoctoral Associates appointed in 1978 are listed below with their universities and the NRL Divisions in which they are working.

- Abe Auerbach (Yale University), Optical Sciences
- Larry R. Barnett (University of Tennessee),
Plasma Physics
- Robert A. Bayles (University of Virginia),
Material Science and Technology
- Robert S. F. Chang (Cornell University), Optical Sciences
- Teresa L. Cole (Brown University), Electronics
Technology

RECOGNITION

Richard A. Coveleskie (University of Illinois), Chemistry
Barry L. Fielek (University of Michigan), Radiation Technology
Marie C. Flanigan (State University of New York, Buffalo), Laboratory for Computational Physics
James W. Fleming (University of North Carolina), Chemistry
John D. Ganjei (Cornell University), Chemistry
Steven H. Gold (University of Maryland), Plasma Physics
Larry P. Goss (University of Georgia), Chemistry
Jeffrey C. Halle (University of Pittsburgh), Chemistry
Roger Hillson (Duke University), Ocean Sciences
Brenda S. Holmes (Howard University), Chemistry
Doren Indritz (Princeton University), Chemistry
Nicholas G. Loter (Massachusetts Institute of Technology), Radiation Technology
Demetrios N. Matsakis (University of California, Berkeley), Space Science
Stephen W. McKnight (University of Maryland), Electronics Technology
Sofia D. Merajver-Siguel (University of Maryland), Optical Sciences
Horace G. Mitchell (Rice University), Plasma Physics
Robert L. Mowery (University of Virginia), Chemistry

Robert J. Nowak (University of Cincinnati), Chemistry
William M. Pitts (University of California, Los Angeles), Chemistry
Mark E. Seaver (Indiana University), Chemistry
Richard C. Shockley (University of Southern California), Laboratory for Computational Physics
Mark R. Skokan (Florida State University), Electronics Technology
Janet L. Smith (University of Wisconsin), Laboratory for Structure of Matter
Arthur W. Snow (City University of New York), Chemistry
Larry D. Talley (University of California), Chemistry
Bruce E. Wilcomb (University of Texas), Optical Sciences

Select Graduate Student Program

To be eligible for this program, employees must have a college degree in an appropriate field and must have maintained at least a "B" average in undergraduate study. Accepted students devote a full academic year to graduate study. While actually attending school, they receive one half of their salaries, and NRL pays for tuition, books, and laboratory expenses. During the summer, they work at the Laboratory and receive normal pay and fringe benefits.

Thirty-four staff members have enrolled in the program since it began in 1967. There were no new students during 1978.

PAPERS, REPORTS, & PATENTS

The collage features several overlapping documents. At the top, a large document is titled "PAPERS, REPORTS, & PATENTS". Below this, there are various technical drawings and mathematical formulas. One document shows a circuit diagram with components labeled "SOURCE", "RESISTOR", and "CAPACITOR". Another document displays a mathematical formula:
$$T = 4 \left(\frac{1}{12 + \frac{1}{10.3}} \right)^2$$
. A third document is titled "United States Patent" and contains a list of references, including "1. MAGNETICALLY TUNED OSCILLATOR" and "2. MAGNETICALLY TUNED OSCILLATOR". The documents are arranged in a way that suggests a process of research and development, from initial reports to final patent applications.

Simple Means of Updating the SRIF Filter in the State Equations are in Triangular

EATON AND SANFORD

Table 1. Component Values for a Pre-amplifier Example

Elementary Disaggregation	Value (% of part)
Q_1	256251.5
Q_2	254467.6
Q_3	240.41
R_1	13.43
R_2	13.8.42
R_3	100.452
R_4	23.7.441
R_5	2.01.45
R_6	66.7.50.5
R_7	150.47
R_8	0.03.4
R_9	49.24.10.4
R_{10}	26.41.16
R_{11}	64.0

Table 2 - DC Analysis of the Prompifier Defined by Fig. 1 and Table 1

Frequency	Gain	I_{out}/I_{in}			
		Minimum	Low	Normal	High
500	31.08	14.00	21.06	44.86	24.00
1000	6.40	0.60	-0.30	2.30	1.20
2000	-3.70	-0.80	-2.10	1.40	-2.00
3000			-9.67	-0.89	-2.21
4000				-18.81	-1.15
5000					-0.81
6000					-1.12

United States Patent

et al. **United States Patent**
[54] **MAGNETICALLY TUNED SURFACE**
[52] **ACOUSTIC WAVE DEVICE**
[72] **Inventors:** Vincent J. Foltz, Washington, D.C.
Caroline Vintar, Reston, Va.; Dhan G.
[73] **Assignee:** Webb, Clegg, MacFarlane & Webb,
Kenneth L. Webb, Alexandria, Va.
[21] **Filed:** May 19, 1978
[51] **Int. Cl.** H01L 27/00
[52] **U.S. Cl.** 333-100; 333-101; 333-102; 333-103; 333-104; 333-105; 333-106; 333-107; 333-108; 333-109; 333-110; 333-111; 333-112; 333-113; 333-114; 333-115; 333-116; 333-117; 333-118; 333-119; 333-120; 333-121; 333-122; 333-123; 333-124; 333-125; 333-126; 333-127; 333-128; 333-129; 333-130; 333-131; 333-132; 333-133; 333-134; 333-135; 333-136; 333-137; 333-138; 333-139; 333-140; 333-141; 333-142; 333-143; 333-144; 333-145; 333-146; 333-147; 333-148; 333-149; 333-150; 333-151; 333-152; 333-153; 333-154; 333-155; 333-156; 333-157; 333-158; 333-159; 333-160; 333-161; 333-162; 333-163; 333-164; 333-165; 333-166; 333-167; 333-168; 333-169; 333-170; 333-171; 333-172; 333-173; 333-174; 333-175; 333-176; 333-177; 333-178; 333-179; 333-180; 333-181; 333-182; 333-183; 333-184; 333-185; 333-186; 333-187; 333-188; 333-189; 333-190; 333-191; 333-192; 333-193; 333-194; 333-195; 333-196; 333-197; 333-198; 333-199; 333-200; 333-201; 333-202; 333-203; 333-204; 333-205; 333-206; 333-207; 333-208; 333-209; 333-210; 333-211; 333-212; 333-213; 333-214; 333-215; 333-216; 333-217; 333-218; 333-219; 333-220; 333-221; 333-222; 333-223; 333-224; 333-225; 333-226; 333-227; 333-228; 333-229; 333-230; 333-231; 333-232; 333-233; 333-234; 333-235; 333-236; 333-237; 333-238; 333-239; 333-240; 333-241; 333-242; 333-243; 333-244; 333-245; 333-246; 333-247; 333-248; 333-249; 333-250; 333-251; 333-252; 333-253; 333-254; 333-255; 333-256; 333-257; 333-258; 333-259; 333-260; 333-261; 333-262; 333-263; 333-264; 333-265; 333-266; 333-267; 333-268; 333-269; 333-270; 333-271; 333-272; 333-273; 333-274; 333-275; 333-276; 333-277; 333-278; 333-279; 333-280; 333-281; 333-282; 333-283; 333-284; 333-285; 333-286; 333-287; 333-288; 333-289; 333-290; 333-291; 333-292; 333-293; 333-294; 333-295; 333-296; 333-297; 333-298; 333-299; 333-300; 333-301; 333-302; 333-303; 333-304; 333-305; 333-306; 333-307; 333-308; 333-309; 333-310; 333-311; 333-312; 333-313; 333-314; 333-315; 333-316; 333-317; 333-318; 333-319; 333-320; 333-321; 333-322; 333-323; 333-324; 333-325; 333-326; 333-327; 333-328; 333-329; 333-330; 333-331; 333-332; 333-333; 333-334; 333-335; 333-336; 333-337; 333-338; 333-339; 333-340; 333-341; 333-342; 333-343; 333-344; 333-345; 333-346; 333-347; 333-348; 333-349; 333-350; 333-351; 333-352; 333-353; 333-354; 333-355; 333-356; 333-357; 333-358; 333-359; 333-360; 333-361; 333-362; 333-363; 333-364; 333-365; 333-366; 333-367; 333-368; 333-369; 333-370; 333-371; 333-372; 333-373; 333-374; 333-375; 333-376; 333-377; 333-378; 333-379; 333-380; 333-381; 333-382; 333-383; 333-384; 333-385; 333-386; 333-387; 333-388; 333-389; 333-390; 333-391; 333-392; 333-393; 333-394; 333-395; 333-396; 333-397; 333-398; 333-399; 333-400; 333-401; 333-402; 333-403; 333-404; 333-405; 333-406; 333-407; 333-408; 333-409; 333-410; 333-411; 333-412; 333-413; 333-414; 333-415; 333-416; 333-417; 333-418; 333-419; 333-420; 333-421; 333-422; 333-423; 333-424; 333-425; 333-426; 333-427; 333-428; 333-429; 333-430; 333-431; 333-432; 333-433; 333-434; 333-435; 333-436; 333-437; 333-438; 333-439; 333-440; 333-441; 333-442; 333-443; 333-444; 333-445; 333-446; 333-447; 333-448; 333-449; 333-450; 333-451; 333-452; 333-453; 333-454; 333-455; 333-456; 333-457; 333-458; 333-459; 333-460; 333-461; 333-462; 333-463; 333-464; 333-465; 333-466; 333-467; 333-468; 333-469; 333-470; 333-471; 333-472; 333-473; 333-474; 333-475; 333-476; 333-477; 333-478; 333-479; 333-480; 333-481; 333-482; 333-483; 333-484; 333-485; 333-486; 333-487; 333-488; 333-489; 333-490; 333-491; 333-492; 333-493; 333-494; 333-495; 333-496; 333-497; 333-498; 333-499; 333-500; 333-501; 333-502; 333-503; 333-504; 333-505; 333-506; 333-507; 333-508; 333-509; 333-510; 333-511; 333-512; 333-513; 333-514; 333-515; 333-516; 333-517; 333-518; 333-519; 333-520; 333-521; 333-522; 333-523; 333-524; 333-525; 333-526; 333-527; 333-528; 333-529; 333-530; 333-531; 333-532;

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The impedance is

$$P = (0.75)^{10} = 0.056$$

$$\hat{P}^{-1} = (\hat{P}^{-1})^T \hat{P}^{-1} \hat{P}^{-1} \quad (21)$$

$$H H' = (H')^{-1} H H' = 1$$

$$A \cdot B = (A \cdot B) \cdot I$$

that $(\phi^{-1})^* \hat{A}$ is lower triangular for ϕ^{-1} and that

(22)

4.088.969

United States Patent
Fisher et al.

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OWN AND TOUR

$$\frac{f_2(R_2 + R_3) + f_3(R_3 + R_4) + \dots + f_n(R_n + R_1)}{2(R_1 + R_2 + \dots + R_n)}$$

(50)

$$R_{11} = \frac{R_{11} + R_{21}}{R_{11} + R_{21} + R_{31} + R_{41}}$$

of Fig. 1 with the com-

BEN H. CANTRELL

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CONTRIBUTIONS

PAPERS, REPORTS, AND PATENTS

NRL's scientists document the results of their research with reports for their sponsors and others concerned with each particular area of investigation. Every year they contribute to a variety of scientific periodicals and books and prepare many special reports, both classified and unclassified. In 56 years, NRL's pioneering research has lead to 2689 patents. The following table summarizes the Laboratory's contributions during 1978 in these areas.

Laboratory staff members are active in most major scientific societies and contribute to them by holding office and serving on committees (see the individual honors under "Recogni-

tion of Personnel") and by making presentations. The latter normally number upward of 1500 and are too numerous to list here. The bibliography that follows contains only the unclassified papers and reports in the table below, grouped according to scientific categories. NRL Memorandum Reports are not listed, except for two that won Research Publication Awards. A dagger preceding a title indicates a prize-winning publication; an asterisk identifies an author who is not on the NRL staff. This section concludes with a list of patents issued to NRL inventors in 1978.

<u>Type of Contribution</u>	<u>Unclass.</u>	<u>Class.</u>	<u>Total</u>
Papers in periodicals, books, and proceedings of meetings	626	47	673
NRL Reports (formal)	67	18	85
NRL Memorandum Reports	145	51	196
Patents granted			49

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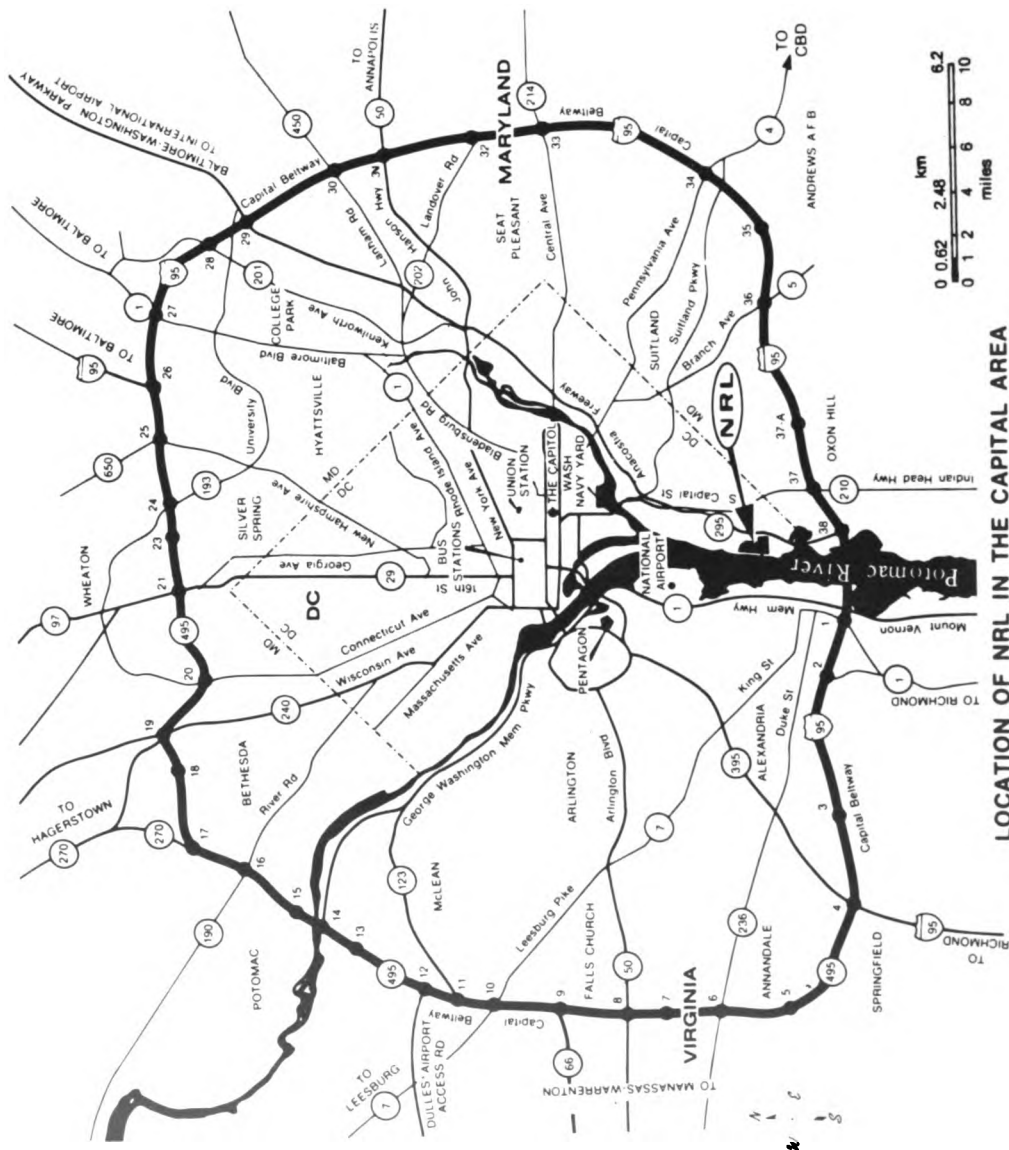
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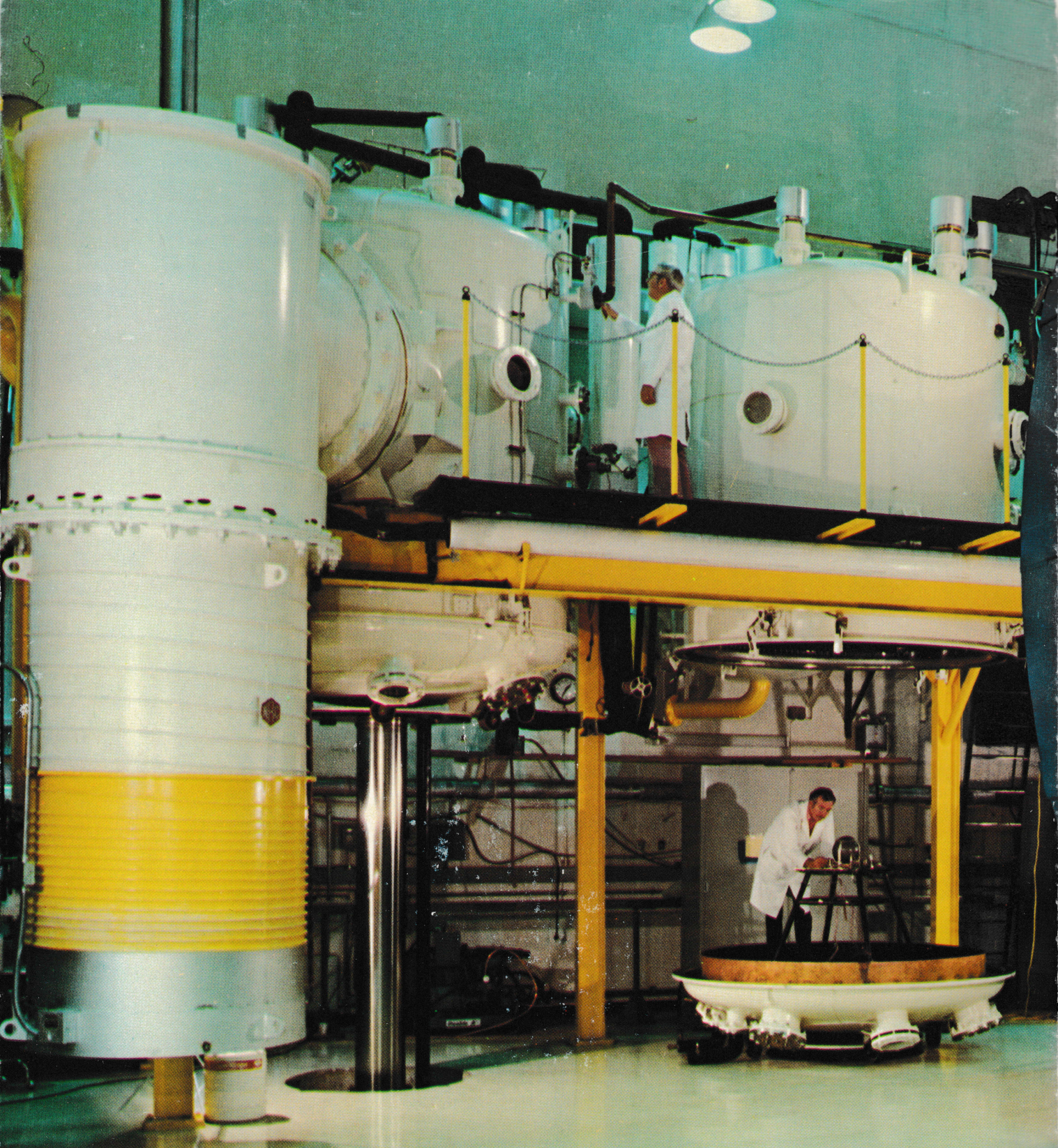
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